

Energy Research and Development Division  
**FINAL PROJECT REPORT**

# **Golden Eagle Monitoring Plan for the Desert Renewable Energy Conservation Plan**

California Energy Commission  
Edmund G. Brown Jr., Governor

March 2018 | CEC-500-2018-008



**PREPARED BY:**

***Primary Author(s):***

J. David Wiens  
Patrick S. Kolar  
Todd E. Katzner

USGS Forest and Rangeland Ecosystem Science Center  
3200 SW Jefferson Way  
Corvallis, Oregon 97331  
Phone: 541-750-0961| Fax: 541-750-8806

***Contract Number: 500-12-007***

***Prepared for:***

**California Energy Commission**

Joseph O'Hagan  
***Contract Manager***

Aleecia Gutierrez  
***Office Manager***  
***ENERGY GENERATION RESEARCH OFFICE***

Laurie ten Hope  
***Deputy Director***  
***ENERGY RESEARCH AND DEVELOPMENT DIVISION***

Drew Bohan  
***Executive Director***

**DISCLAIMER**

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

## **ACKNOWLEDGEMENTS**

The authors thank the California Energy Commission for support and funding. The authors especially thank Sue Phillips at the USGS Forest and Rangeland Ecosystem Science Center for her contributions to this project. Nathan Schumaker, Rich Inman, Todd Esque, Kathleen Longshore, and Ken Nussear contributed to developing and testing the demographic model presented in Chapter 3. The authors also thank the participants of the Desert Renewable Energy Conservation Plan (DRECP) Golden Eagle Monitoring Plan Meeting for their helpful guidance during initial planning and development of the monitoring plan. The authors thank Jessi Brown, Susan Salafsky, Brian Woodbridge, and three anonymous reviewers for their helpful edits and review comments. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

## PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

*Golden Eagle Monitoring Plan for the Desert Renewable Energy Conservation Plan Area* is a final report for the Golden Eagle Survey and Monitoring Protocol for the Desert Renewable Energy Conservation Plan (contract number 500-12-007) conducted by U.S. Geological Survey. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at [www.energy.ca.gov/research/](http://www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

## ABSTRACT

This report describes options for monitoring the status and population trends of the golden eagle (*Aquila chrysaetos*) within the Desert Renewable Energy Conservation Plan (DRECP) area of Southern California in maintaining stable or increasing population in the planning area. The report profiles the ecology of golden eagles in the region and provides a range of potential sampling options to address monitoring needs and objectives. This approach also focused on links between changes in human land-use, golden eagle nesting and foraging habitat conditions, and population dynamics. The report outlines how monitoring data from demographic, prey, and habitat studies were used to develop a predictive demographic model for golden eagles in the DRECP area. Results from the model simulations suggest increases in renewable energy development could have negative consequences for population trajectories. Results also suggest site-specific conservation actions could reduce the magnitude of negative impacts to the local population of eagles.

A monitoring framework is proposed including: (1) annual assessments of site-occupancy and reproduction by territorial pairs of golden eagles (including rates at which sites become colonized or vacated over time); (2) estimates of survival, movements, and intensity of use of landscapes by breeding and non-breeding golden eagles; (3) periodic (conducted every two to four years) assessments of nesting and foraging habitats, prey populations, and associations with land-use and management activities; and (4) updating the predictive demographic model with new information obtained on eagles and associated population stressors.

The results of this research were published in the *Journal of Raptor Research*, Wiens, David, Inman, Rich D., Esque, Todd C., Longshore, Kathleen M. and Nussear, Kenneth (2017). Spatial Demographic Models to Inform Conservation Planning of Golden Eagles in Renewable Energy Landscapes. 51(3):234-257.

**Keywords:** Golden eagle, *Aquila chrysaetos*, renewable energy, wind, solar, decision support, Desert Renewable Energy Conservation Plan

Please use the following citation for this report:

Wiens, J.D. et al. 2017. *Golden Eagle Monitoring Plan for the Desert Renewable Energy Conservation Plan Area*. California Energy Commission. Publication number: CEC-500-2018-008.

## TABLE OF CONTENTS

<b>Acknowledgements .....</b>	<b>i</b>
<b>PREFACE .....</b>	<b>ii</b>
<b>ABSTRACT .....</b>	<b>iii</b>
<b>TABLE OF CONTENTS.....</b>	<b>iv</b>
<b>LIST OF FIGURES .....</b>	<b>vi</b>
<b>LIST OF TABLES .....</b>	<b>vi</b>
<b>EXECUTIVE SUMMARY .....</b>	<b>1</b>
Introduction .....	1
Project Purpose .....	1
Project Process and Results.....	1
Recommendations.....	2
California Benefits.....	3
<b>CHAPTER 1: Introduction.....</b>	<b>5</b>
1.1 Background.....	5
1.2 Steps in Developing the Golden Eagle Monitoring Plan.....	8
1.3 Definitions.....	9
1.4 Monitoring Questions and Objectives.....	10
<b>CHAPTER 2: Conceptual Model of Population Indicators.....</b>	<b>11</b>
2.1 Conceptual Model Purpose and Development.....	11
2.2 Population Limiting Factors .....	11
2.3 Application to Golden Eagles in the Plan Area .....	11
2.4 Indicators Proposed for Monitoring.....	13
<b>CHAPTER 3: Golden Eagle Predictive Demographic Model .....</b>	<b>15</b>
3.1 Need and Application .....	15
3.2 Model Development and Population Simulations .....	16
3.2.1 Nesting Habitat .....	18
3.2.2 Prey Availability.....	19

3.2.3	Population Simulation Model .....	19
3.2.4	Potential Effects of Energy Development .....	24
3.2.5	Simulations and Model Assessment.....	25
3.3	Simulation Results and Model Assessment .....	26
3.3.1	Emergent Population Dynamics .....	31
3.3.2	Potential Effects of Energy Development .....	32
3.4.	Synthesis and Conclusions .....	32
3.4.1	Potential Effects of Energy Development .....	36
3.4.2	Model Uncertainties and Refinement .....	38
3.5	Applications for Monitoring and Conservation .....	39
<b>CHAPTER 4: Overview of Monitoring Options .....</b>		<b>41</b>
4.1	Population and Habitat-based Monitoring Strategies .....	41
4.1.1	Options for Population Monitoring.....	41
4.1.2	Habitat-Based Monitoring .....	50
<b>CHAPTER 5: Proposed Monitoring Approach.....</b>		<b>52</b>
5.1	Population and Habitat Monitoring, Phases I and II .....	54
5.2	Recommended Sampling Options .....	55
5.2.1	Surveys of Site Occupancy, Reproduction, and Abundance .....	55
5.2.2	Non-invasive Mark-recapture Studies .....	55
5.2.3	Long-Term Monitoring at Multiple Spatial Scales .....	56
<b>CHAPTER 6: Implementation and Refinement .....</b>		<b>58</b>
6.1	Proposed Survey Design and Field Protocols.....	58
6.1.1	Survey Level Descriptions and Inferences .....	58
6.1.2	Estimation of Occupancy, Reproduction, and Intensity of Use .....	58
6.1.3	Standardized Survey Protocol.....	62
6.2	Expected Conditions and Trends.....	62
6.3	Reporting and Implementation Schedule.....	62
<b>GLOSSARY .....</b>		<b>64</b>

REFERENCES .....	65
APPENDIX A: Report on the DRECP Golden Eagle Monitoring Plan Meeting .....	A-1
APPENDIX B: Baseline Parameter Values of the Golden Eagle Predictive Demographic Model. ....	B-1
APPENDIX C: A Standardized Survey Protocol for Gathering Data on Site Occupancy, Reproduction, and Use of Landscapes by Golden Eagles.....	C-1

## LIST OF FIGURES

Figure 1: Golden Eagle ( <i>Aquila chrysaetos</i> ) in the Mojave Desert.....	6
Figure 2: Historical Nest Locations Used by Golden Eagles in the DRECP Area, California.....	7
Figure 3: Conceptual Model of Population Limiting Factors for Golden Eagles in the DRECP Area, California .....	12
Figure 4: Spatial Data Used to Inform the Golden Eagle Predictive Demographic Model for the DRECP Area, California.....	17
Figure 5: Life Cycle of the Simulated Population of Golden Eagles in the DRECP Area, California.....	20
Figure 6: Modeling Sequence of an Individual-based, Spatially Explicit Simulation Model for Golden Eagles in the DRECP Area, California .....	21
Figure 7: Output from the Stable, Baseline Population Simulation Model for Golden Eagles in the DRECP Area, California .....	27
Figure 8: Predicted Distribution of Long-term Productivity and Mortality in Breeding Ranges of Golden Eagles in the DRECP Area, California .....	31
Figure 9: Predicted Population Response of Golden Eagles in the DRECP Area, California, to Different Risk Scenarios Associated with Planned Energy Development.....	33
Figure 10: Example of the Multistate Occupancy Sampling Design.....	61

## LIST OF TABLES

Table 1: Mean Values of Demographic Parameters Obtained from the Stable, Baseline Demographic Model for Golden Eagles in the DRECP Area, California, as Compared to Observed Values from Local Field Studies .....	28
Table 2: Sensitivity of the Stable, Baseline Demographic Model for Golden Eagles in the DRECP Area, California, to Incremental Changes in Uncertain Model Parameters .....	30
Table 3: Estimates of Mean Pre- and Post-disturbance Population Sizes from Replicate Simulations of Different Hypothesized Effects of Future Renewable Energy Development on Golden Eagles in the DRECP Area, California .....	34
Table 4: Assessment Capabilities of Alternative Sampling Approaches Considered for Monitoring Population Trend of Golden Eagles in the DRECP Area, California.....	49



Table 5: Simulation Results for a Range of Potential Survey Designs Considered for Estimating Site Occupancy ( $\psi^1$ ), and Reproduction ( $\psi^2$ ) of Golden Eagles in the DRECP Area. ....	60
---	----

# EXECUTIVE SUMMARY

## Introduction

The golden eagle (*Aquila chrysaetos*) is a protected species specifically targeted for conservation under the Desert Renewable Energy Conservation Plan (DRECP). Developing wind and solar energy projects in areas used by golden eagles in the DRECP area poses a unique challenge to land managers because of this species' vulnerability to collisions with wind turbines and sensitivity to increases in human land-use. In addition, infrastructure associated with wind and solar energy projects, especially roads and power lines, also cause direct mortality to golden eagles through collisions with vehicles or electrocutions from power poles.

Research and monitoring of golden eagles are necessary to ensure that the biological goals and standards of the DRECP are achieved while promoting wildlife-compatible renewable energy development. It is generally recognized that two types of monitoring are required by regulatory officials for golden eagles in the DRECP area: population trend monitoring and project-level monitoring of fatality rates. This report focuses on monitoring population status and trends.

## Project Purpose

The goal of the Golden Eagle Monitoring Plan is to evaluate the effectiveness of the DRECP in maintaining populations in the plan area. The monitoring plan provides timely ecological information that can be used to guide future actions that minimize the impacts of renewable energy development and other human-caused stressors to golden eagles and their habitats. Objectives of the Golden Eagle Monitoring Plan are to: (1) assess change in population trends and factors associated with corresponding changes in proposed indicators of population status (territory occupancy, reproduction and survival); (2) assess the potential for anticipated changes in human land-use to affect vital rates of golden eagles and their nesting and foraging habitats; and (3) develop a predictive demographic simulation model linking population dynamics of golden eagles, known threats, status of nesting and foraging habitats, and anticipated changes in land-use.

## Project Process and Results

The Golden Eagle Monitoring Plan profiled the ecology and status of golden eagles and their habitats in the DRECP area, described a range of options to address monitoring and research needs, and presented an adaptive monitoring approach focused on links among human land-use, environmental conditions, and population dynamics of golden eagles. Based on a review of potential sampling options, the team proposed a monitoring framework that included four main components: 1) annual assessments of site-occupancy and reproduction by territorial pairs of golden eagles (including rates at which sites become colonized or vacated over time); 2) estimates of survival, movements, and intensity of use of landscapes by breeding and non-breeding golden eagles; 3) periodic (conducted every two to four years) assessments of nesting and foraging habitats, prey populations, and associations with land-use and management activities; and 4) updating the baseline predictive demographic model with new information obtained on eagles and associated population stressors.

To help guide initial monitoring efforts and synthesize demographic information on eagles, the authors developed a demographic simulation model that integrated empirical demographic data on golden eagles with spatial information on the arrangement of nesting habitats, prey resources, and planned renewable energy development sites in the study region. The team used the model to explore potential effects of alternative development scenarios and conservation strategies on the future distribution and abundance of golden eagles. Simulation results indicated probable increases in deaths of golden eagles caused by developing renewable energy infrastructure (such as collisions with wind-turbines and vehicles, electrocutions on power poles) could have negative consequences for population trajectories. Results also show how site-specific conservation actions (for example seasonal curtailment of wind turbines, power pole retrofitting to lessen electrocution risk) could significantly reduce the magnitude of negative impacts to golden eagles. Output from the demographic model identified specific areas in the plan area that may contribute most to overall productivity of the local population, thereby providing an initial guide to prioritize monitoring and conservation efforts.

Simulation results from the predictive demographic model provided relevant expectations for the response of golden eagle populations, and their habitats, to the planned increases in renewable energy development in the plan area. These expectations include:

- The local population of golden eagles may experience declines over the short term, caused by probable increases in subadult and adult fatalities associated with implementing renewable energy projects.
- In the long term, the local population is likely not self-sustaining as it is heavily reliant upon external recruitment from other areas to maintain numbers of breeding eagles.
- Quality of existing foraging habitats associated with future development focal areas will generally decline, but it remains unclear how mortality rates will be affected in these areas if use of these sites by individual eagles also declines as a result of decreased prey availability.

The team proposed a monitoring framework relying on broad-scale, standardized population surveys of breeding and non-breeding eagles coupled with more detailed studies of survival and movements. Together, these studies provided precise and accurate estimates of the status and trend of the local population of golden eagles over time. Key components of data collection, analysis, and reporting during implementing the proposed monitoring plan are detailed demographic studies and annual surveys of breeding and non-breeding golden eagles. A standardized survey design and field protocols are provided for annual assessments of site occupancy, reproduction, and abundance of golden eagles.

Observed estimates of population status and trend derived from newly collected survey data can be compared with expected values derived from the demographic model to strengthen the predictive capabilities of the model.

The results of this research were published in the *Journal of Raptor Research*, Wiens, J. David, Inman, Rich D., Esque, Todd C., Longshore, Kathleen M. and Nussear, Kenneth (2017). Spatial

Demographic Models to Inform Conservation Planning of Golden Eagles in Renewable Energy Landscapes. 51(3):234-257.

## **Recommendations**

The research team recommends that golden eagle population surveys include a site-occupancy design capable of providing precise estimates of occupancy, reproduction, abundance, and the rate of change in occupancy parameters. The design should account for imperfect detection of golden eagles during surveys, and permit the use of newer analytical methods can be applied to estimate relevant parameters such as population gains and losses. In particular, noninvasive recapture methods, such as collecting feathers for genetic analysis could be used to estimate and monitor changes in survival of territorial eagles. Finally, the team recommends that long-term monitoring at multiple sites be coupled with regional surveys of the broader golden eagle population. These regional surveys of population size provide broader information relevant to national survey efforts for golden eagles.

## **California Benefits**

This project benefitted ratepayers by promoting the State of California's renewable energy goals and clean energy jobs, while helping to protect golden eagles and associated desert ecosystems. To meet the goals of the DRECP, and to promote compliance with the federal Bald and Golden Eagle Protection Act, research and monitoring must be completed to measure and assess population and habitat conditions. Monitoring population trends of golden eagles allow federal and state regulatory officials to determine the appropriate number of permits to issue for take requests by renewable energy projects while ensuring a sustainable population.

Localized estimates of territory occupancy, reproduction, survival, and population size can provide regulatory agencies with information necessary to make sound conservation policy regarding site-specific permitting of renewable energy projects. With a better understanding of the sensitivity of golden eagles to renewable energy development, wildlife managers and industry planners will effectively know which indicators to consider when planning for the conservation of golden eagles and their habitats in the context of siting future energy facilities. This information ensures stable and reliable sources of renewable energy can be provided to California residents in an environmentally responsible manner.



# CHAPTER 1: Introduction

## 1.1 Background

Developing renewable energy resources must increase dramatically if California is to meet goals of providing greater retail electricity sales through renewable sources of energy (CA Senate Bill SB X1-2, Simitian, Chapter 1, Statutes of 2011). In particular, the Mojave and Sonoran Deserts of southern California have been targeted for rapid development of renewable energy because of the region's abundant wind and solar irradiation potential. To provide permitting of renewable energy projects while minimizing potential impacts to unique desert ecosystems, the California Energy Commission, along with several other state and federal agencies and stakeholders, developed the Desert Renewable Energy Conservation Plan (DRECP; CEC 2011, 2014). The goal of the DRECP is to provide for effective protection and conservation of unique desert ecosystems while allowing for the streamlined development of renewable energy projects. The DRECP has 11 planning goals<sup>1</sup>, but three of those goals most relevant to this report are:

- Provide for the long-term conservation and management of Covered Species within the planning area;
- Identify the most appropriate locations within the planning area for the development of utility-scale renewable energy projects, taking into account potential impacts to threatened and endangered species and sensitive natural communities; and
- Provide a comprehensive means to coordinate and standardize mitigation and compensation requirements for covered activities within the planning area.

The golden eagle (*Aquila chrysaetos*; Figure 1) is a species targeted for conservation under the DRECP that may be sensitive to environmental changes associated with development of wind and solar energy projects (CEC 2014). Development of wind-energy in areas occupied by golden eagles poses a unique challenge to land managers because of this species' vulnerability to collisions with wind turbines and sensitivity to changes in human land-use (Hunt 2002, Pagel et al. 2013, Kochert and Steenhof 2002, Steenhof et al. 2014). Potential risks from solar developments are likely to be indirect, occurring through loss of foraging habitat and prey availability (Holroyd et al. 2010), although solar concentrating facilities may cause direct mortality via collisions with structures or from heat-related burns (Kagan et al. 2014, Walston et al. 2016). Infrastructure associated with wind and solar energy projects, especially roads and power lines, can be a significant cause of mortality in golden eagles through collisions or electrocutions (Lehman et al. 2010, Hunt et al. 2017). Breeding golden eagles are also sensitive to disturbance from recreational activities (Martin et al. 2009, Spaul and Heath 2016).

---

<sup>1</sup> <http://www.drecp.org/index.html>

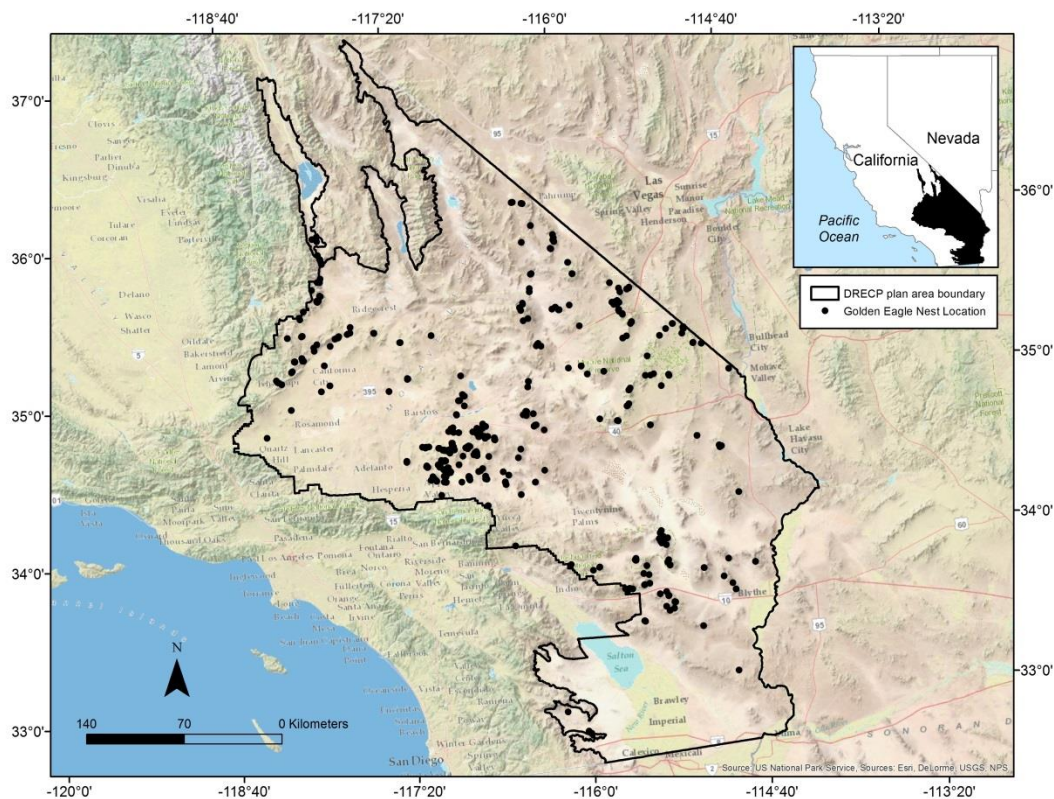
**Figure 1: Golden Eagle (*Aquila chrysaetos*) in the Mojave Desert**



Photo Credit: Kathleen Longshore

Golden eagles are currently afforded protection under the Bald and Golden Eagle Protection Act (Eagle Act Standard; 16 U.S.C. 668 – 668d). The U.S. Fish and Wildlife Service (USFWS) recently proposed changes to the Eagle Act Standard to include modifications to regulations governing incidental take permits for bald and golden eagles (USFWS 2016). To promote compliance with federal and state laws protecting eagles, and to determine issuance criteria of take permits for renewable energy projects, the USFWS developed the Eagle Conservation Plan Guidance Module 1: Wind Energy Development (ECPG). The ECPG provides guidance for renewable energy projects on determining presence and use of proposed and existing project sites by golden eagles (USFWS 2013). Jointly, the two conservation plans (DRECP, ECPG) inform California's renewable energy strategy. A key objective of both conservation plans is to monitor population size and trends of golden eagles so that regulatory officials can determine the appropriate number of permits to issue for take requests by renewable energy projects while ensuring a sustainable breeding population. Research and monitoring is necessary to ensure biological goals and standards of the DRECP will be achieved while promoting compatible renewable energy development (CEC 2014). Specifically, monitoring of golden eagles is required to: (1) assess trends in the golden eagle population relative to goals of maintaining stable or increasing breeding populations; (2) promote effective golden eagle conservation and compatible renewable energy development; and (3) determine if management actions, including compensatory mitigation, are meeting the goals of the DRECP and Eagle Act Standard.

**Figure 2: Historical Nest Locations Used by Golden Eagles in the DRECP Area, California**



There is currently little information available on the population status of golden eagles in areas targeted for conservation under the DRECP. Recent surveys indicate that nests historically used by golden eagles are patchily distributed in the plan area (Figure 2; Latta and Thelander 2013, George et al. 2014). Golden eagles occur in open savannas and shrub-steppe landscapes in the region, but they also breed in nearby mountain ranges with open forest and deserts (Brown 2014). Non-breeding eagles, including non-territorial subadults or adult floaters (i.e., breeding-aged individuals that are prevented from reproducing by lack of a territory or nesting opportunities; Steenhof and Newton 2007), or birds on migration or during winter also use the Plan area. Availability of sufficient nesting substrates, such as cliffs, large trees, or transmission towers, can limit the distribution of breeding territories, and, ultimately, population size (Watson 2010, Brown 2014). Historically, golden eagles occurred in open habitats of deserts throughout the region, though detailed data on the distribution of breeding pairs are lacking (reviewed by Brown 2014). More recently, local telemetry studies showed that resident golden eagles expanded their home ranges in hot summer months to include cooler, mountainous areas proximate to the Plan area (Braham et al. 2015). This finding is relevant because it suggests that prudent conservation measures for resident golden eagles in the DRECP area will consider risks and benefits to eagles encountered outside of the plan area. These findings also indicate that



seasonal variation in movement behaviors could influence the ability to detect the birds at their breeding sites and determine breeding status during population surveys (Braham et al. 2015).

Two types of monitoring have been outlined for golden eagles in the DRECP area: population trend monitoring and project-level monitoring of fatality rates (CEC 2014). This report focuses on population trend monitoring. Estimating population size and trend of golden eagles over time requires: 1) a rigorous sampling design to avoid biases; 2) measurements that are precise enough to detect trends; and 3) analyses that can reliably separate changes in the factors of interest from other confounding sources of variation. Despite the need for detailed population assessments of golden eagles, it is unclear what specific tools will provide land managers with the information needed to minimize risks to golden eagles while permitting as many renewable energy projects as possible. Most existing long-term information on golden eagles in western North America is from studies that tracked trends in site-occupancy and reproduction of breeding pairs in local populations (e.g., Kochert and Steenhof 2002, Martin et al. 2009). Such information provides valuable insights about the ecological response of breeding eagles to site-specific conditions, but these types of studies may not adequately address the question of whether a local population of eagles has the demographic resiliency to absorb additive stressors associated with rapid renewable energy development. In addition, many past monitoring programs focused only on the breeding segment of eagle populations, which fails to account for non-breeding floaters that can quickly replace breeder mortality and complicate interpretations of population status. Alternative methods based on aerial line-transect surveys provide estimates of total population size (Good et al. 2007, Millsap et al. 2013, George et al. 2014, Duerr et al. 2015), but these approaches may not provide sufficient precision to reliably detect relevant changes to both breeding and non-breeding segments of the local population. These uncertainties indicate that multiple life-history stages and demographic parameters of golden eagles will need to be monitored to ensure both short- and long-term changes to the local population are detected. As a consequence, a combination of monitoring tools is likely to be required to ensure that established conservation goals for golden eagles are being met.

## **1.2 Steps in Developing the Golden Eagle Monitoring Plan**

The approach to developing a proposed monitoring framework for golden eagles in the plan area was built upon general recommendations for the design and implementation of a monitoring program for sensitive species by Mulder et al. (1999). This approach was developed to provide a monitoring framework for sensitive avian species targeted for conservation under the Northwest Forest Plan, including the northern spotted owl (*Strix occidentalis caurina*; Lint et al. 1999) and marbled murrelet (*Brachyrhamphus marmoratus*; Madsen et al. 1999). The Golden Eagle Monitoring Plan uses an adaptive approach to monitoring focused on linkages between human land-use, environmental conditions, and population dynamics of eagles. Following are six steps (modified from Mulder et al. 1999) of the proposed monitoring framework. Specific reference points in the monitoring plan that relate to each step are also provided.

**Step 1: Specify monitoring goals and data needs.** This step was accomplished via a multiagency DRECP Golden Eagle Monitoring Plan Meeting. Representatives of management

and regulatory agencies responsible for implementing the DRECP met with scientists specializing in golden eagle ecology and survey methods to clarify objectives and expected uses of monitoring data. The outcome of this meeting was: 1) a set of monitoring objectives; 2) an outline of data needs; and 3) a general strategy to monitor golden eagles in the plan area. See Chapter 1: “Monitoring Questions and Objectives” and Chapter 4: “Population and Habitat based Monitoring Strategies”. A report detailing meeting objectives, outcomes, and participants is also provided in Appendix A.

**Step 2: Identify primary threats and develop conceptual models linking threats to population dynamics of golden eagles.** See Chapter 2: “Conceptual Model of Population Indicators”.

**Step 3: Identify and select candidate indicators that reflect fundamental demographic processes and state of the golden eagle population.** See Chapter 2: “Conceptual Model of Population Indicators”, and Chapter 3: “Golden Eagle Predictive Demographic Model”. Here, the predictive demographic model is: 1) used to help identify specific vital rates that are most important to monitor given the current knowledge of the eagle population and anticipated development; and 2) continuously updated and refined as new demographic information is collected, thereby providing a quantitative support tool for land management decisions in the Plan area that may affect eagles.

**Step 4: Establish sampling designs to estimate status and trend of essential demographic parameters and candidate indicators over space and time.** See Chapter 4: “Overview of Monitoring Options”, Chapter 5: “Proposed Monitoring Approach”, and Appendix C: “Proposed Sampling Design”.

**Step 5: Conduct periodic assessment of linkages between threats, habitat characteristics, population dynamics, and management actions.** See Chapter 3: “Golden Eagle Predictive Demographic Model” and Chapter 5: “Proposed Monitoring Approach”.

**Step 6: Ensure link to adaptive management and decision-making.** The monitoring plan is viewed as a work in progress, to be updated as new knowledge and information is gained about the population status of golden eagles and associations with renewable energy. Step 6 emphasizes the importance of an adaptive monitoring approach capable of quickly embracing new information or unexpected threats as necessary. See Chapter 6: “Implementation and Refinement of the Monitoring Plan”.

## **1.3 Definitions**

Differing concepts and interpretations of habitat have caused significant confusion and uncertainty in the interpretation of the scientific literature (Hall et al. 1997, Morrison et al. 2006, Krausman and Morrison 2016). For the purposes of this monitoring plan, habitat for golden eagles includes those areas with the full suite of resources (e.g., abundant prey, nest substrates) and environmental conditions (e.g., vegetation, climate) suitable for occupancy, reproduction, and survival of the species (*sensu* Morrison et al. 2006). For example, one critical component of habitat for golden eagles is the availability of suitable substrates to build their large nesting structures, while at broader spatial scales habitats used by the birds are typically evaluated in

terms of physiographic conditions most suitable for foraging or dispersal. A more holistic definition of habitat considers other environmental conditions, such as abundance of prey or competitors, weather, and climate.

## **1.4 Monitoring Questions and Objectives**

The Golden Eagle Monitoring Plan evaluates the effectiveness of the DRECP in maintaining populations and habitats of golden eagles in the plan area. The monitoring plan is intended to provide timely ecological information that can be used to inform future actions that reduce possible impacts of energy development to eagles and their habitats.

The monitoring plan is centered on a specific set of management-based questions about conservation of golden eagles in the plan area. These questions were developed and agreed upon by regulatory officials and scientists at the multiagency DRECP golden eagle monitoring plan meeting (see Appendix A), and included:

- Will implementation of the Conservation Plan meet the goals of the DRECP and Eagle Act Standard in maintaining stable or increasing populations of golden eagles?
- What is the trend in vital rates of golden eagles (e.g., territory occupancy, adult survival, reproduction) in the planning area? Do these trends support a conclusion that the DRECP is working to achieve stable or increasing populations?
- How do renewable energy development and other anthropogenic stressors interact to influence golden eagles in the plan area?

Given the goal and monitoring questions identified above, specific objectives of the golden eagle monitoring plan are to:

- 1) Assess change in population trend and factors associated with corresponding changes in key vital rates (site occupancy, survival, reproduction).
- 2) Assess change in the amount and distribution of suitable nesting and foraging habitat conditions for golden eagles in the plan area.
- 3) Develop a predictive demographic simulation model linking population dynamics of golden eagles to multiple interacting threats, status of nesting and foraging habitats, and anticipated changes in land-use.

The predictive demographic model specified under Objective 3 serves two important purposes:

1) to inform which vital rates are likely to be most important to monitor, given the current knowledge of the eagle population in the beginning stages of monitoring; and 2) to provide a quantitative decision-support tool that is continuously updated as new information on eagles and their habitats is collected in the plan area.

## **CHAPTER 2:**

# **Conceptual Model of Population Indicators**

### **2.1 Conceptual Model Purpose and Development**

An initial task in developing the monitoring plan was to select indicators that reflect the underlying processes governing population dynamics, which can be facilitated by the development of a conceptual model (Lint et al. 1999, Mulder et al. 1999). The indicators are attributes that directly characterize the state of the population, or characterize the structural and compositional resources that determine population status. The conceptual model outlines known and hypothesized connections among ecosystem processes (e.g., climate, landscape disturbance), resources (e.g., food, nesting sites), and population dynamics of golden eagles. Development of the model began with a list of potential candidate indicators linking environmental conditions to abundance, distribution, and vital rates (i.e., survival and reproduction). This list included biotic and abiotic features of the environment that may interact across multiple spatial and temporal scales to limit population size. Next, potential limiting factors were linked according to their potential effect on the population in terms of survival, reproduction, and movement, in addition to potential effects on food and nesting resources. The resulting conceptual model illustrated the dynamic relationships among population limiting factors of golden eagles and their habitats in the plan area (Figure 3).

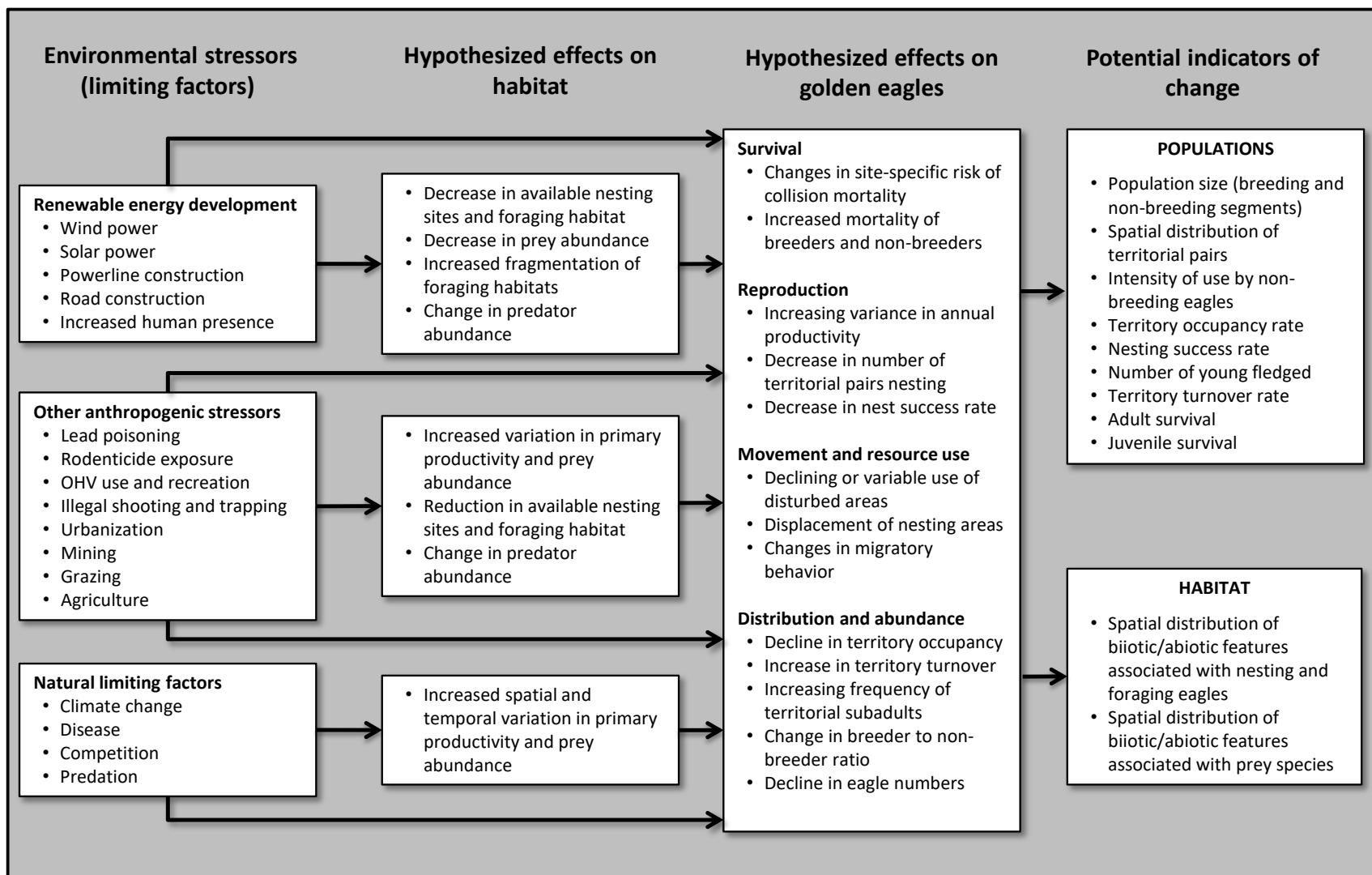
### **2.2 Population Limiting Factors**

Questions relevant to conservation of golden eagles involve factors that limit their distribution and abundance. Such factors include biotic and abiotic features of the environment that affect individual fitness and important population processes like survival and reproduction. Golden eagles are normally regulated by interactions between resource levels, climate, and density-dependent factors, but human impacts such as disturbance, exposure to contaminants, or persecution may accentuate these factors and lead to reduced viability. Disturbance, whether natural or human-induced, can also affect populations by changing the abundance and availability of resources, which in turn may influence other ecological relationships such as competition or disease. Selection of individual- and landscape-scale indicators for monitoring was based on literature review, expert opinion, and preliminary inferences drawn from a population simulation model (see Chapter 3: Golden Eagle Predictive Demographic Model).

### **2.3 Application to Golden Eagles in the Plan Area**

During preliminary meetings with regulatory officials and biologists, it was recognized that the DRECP area may not necessarily be a biologically relevant scale to golden eagles, but that monitoring at this scale is still necessary to meet all Renewable Energy Action Team agency regulatory needs (Appendix A). As a result, the monitoring plan largely focuses on the relationship between renewable energy development and localized population dynamics of golden eagles in the plan area (including breeding, resident non-breeding, migrating, and wintering eagles; USFWS 2013).

**Figure 3: Conceptual Model of Population Limiting Factors for Golden Eagles in the DRECP Area, California**



Shown are the potential direct and indirect pathways by which natural and human-induced stressors (population limiting factors) may interact to affect golden eagles and their habitats in the Desert Renewable Energy Conservation Plan area, California

In addition to direct consequences of renewable energy development to the local population, the conceptual model illustrates potential changes in habitat availability (i.e., loss of breeding sites and foraging areas) as a limiting factor. For this reason, potential indicators of population change in the plan area are presented in two broad categories – populations and habitat (Figure 3). Here, the consequences of changes in habitat conditions caused by human disturbance can be assessed directly by measuring various demographic rates of golden eagles, or indirectly by measuring environmental attributes (e.g., prey availability) predicted to be tightly correlated with demographic rates of eagles.

Measurement of and inferences about populations of golden eagles are influenced by the scale of observation. The conceptual model outlined above was considered over three spatial scales to capture potential scale-dependent effects of environmental stressors on golden eagles:

- **Territory scale:** focuses on landscape change processes within individual breeding territories (i.e., project-level effects on nest sites and foraging areas of breeding individuals). This scale highlights the distinction among territories with high versus low probability of occupancy, reproductive output, and survival.
- **Planning area (DRECP) scale:** focused on cumulative changes at the landscape scale of the plan area, and how these changes influence size and distribution of the local breeding population of golden eagles. At this scale, cumulative changes in habitat may indirectly affect resource use, reproduction, and survival across multiple breeding sites.
- **Regional and national scale:** links changes in the local population of golden eagles in the plan area to changes in the regional or national population (or meta-population). This scale is focused on cumulative change in populations and/or habitats across multiple physiographic regions of the western U.S., and how those changes may ultimately affect results of a localized monitoring program.

## 2.4 Indicators Proposed for Monitoring

Indicators of population status and trend should:

- Be representative of the state of the focal population.
- Reflect fundamental population processes and changes.
- Be measureable and quantifiable.
- Show a high likelihood of detecting changes in the state of the ecosystem.
- Have reasonable measurement costs.

The conceptual model for golden eagles focuses primarily on anthropogenic stressors and availability of resources as the prime determinants of the species' population dynamics. Based on the conceptual model and selection criteria specified above, indicators of population status and trend proposed for monitoring include:

1. Population size (numbers of breeding and non-breeding individuals).
2. Survival (includes estimation of adult and pre-adult mortality).
3. Reproduction (annual proportion of sites monitored with  $\geq 1$  young fledged, and the number of young fledged per site per year).
4. Site occupancy (annual proportion of survey sites with detections of territorial pairs of eagles and/or subadult eagles).
5. Territory turnover (includes estimation of the frequency at which territorial individuals are replaced at known breeding sites – an indicator of high site-specific mortality).

Indicators of status and trend in habitat conditions include:

1. Amount and distribution of nesting habitat (includes availability of nesting substrates).
2. Amount and distribution of foraging habitat (includes the physiographic conditions that facilitate prey availability and prey acquisition by eagles).
3. Density and distribution of primary prey species.

# CHAPTER 3:

## Golden Eagle Predictive Demographic Model

By J. David Wiens, N.H. Schumaker, R.D. Inman, T.C. Esque, K.M. Longshore, and K.E. Nussear

### 3.1 Need and Application

Life-history of golden eagles is characterized by high survival of long-lived territorial adults (Kochert et al. 2002), but relatively low annual reproduction (Watson 2010), and a delayed age at first breeding (4 – 7 years old; Steenhof et al. 1997, 2014). These life history traits make it difficult for short-term field studies to quantify impacts of potential threats associated with renewable energy development, because long time lags may separate disturbance events from their population-level consequences (Krauss et al. 2010, Hylander and Ehrlén 2013). In addition, emergent risks from energy development may interact with existing, more pervasive threats (e.g., lead or rodenticide contamination; Herring et al. 2017), making it especially difficult for traditional field studies to identify the relative importance of different anthropogenic threats.

Forecasting population responses of golden eagles to an increasing array (or intensity) of anthropogenic threats is complicated because individual contributions to population dynamics vary depending on age, social status, and the ability to acquire resources in spatially variable environments. Mechanistic population models provide a means to address this conundrum because: 1) they provide a standardized framework for integrating empirical data with expert knowledge and biological intuition, and 2) they are ideally suited for developing, testing, and communicating hypotheses and predictions about the relative influence of multiple interacting stressors (Munns 2006, Schumaker et al. 2014, Stenglein et al. 2015, Tuma et al. 2016). Additionally, the process of developing a mechanistic population model demands that authors make explicit assumptions about system dynamics, which ultimately enhances transparency within a management context (Turner et al. 1995, Grimm 1999). This process allows researchers to synthesize and extend knowledge gained from empirical field studies while allowing managers and stakeholders to understand and utilize scientific information in the pursuit of effective conservation policy (Katzner et al. 2007, Schmolke et al. 2010, Albeke et al. 2015).

Empirical data on population indicators identified in Chapter 2, and information on population trends of golden eagles in the plan area, were lacking. As a consequence, a spatially-explicit, individual-based model was developed to explore potential interactions between existing threats, planned increases in renewable energy development, and population dynamics of golden eagles in the DRECP area. The goal was to develop a flexible modeling framework that can aid in the spatial conservation prioritization of golden eagles exposed to increases in renewable energy development and other potential threats. The baseline population model included stage-specific survival, reproduction, movement, and resource use of golden eagles that was informed by spatial data on nesting habitats and prey availability derived from field studies conducted in the study area. Model assumptions were evaluated with empirical data, and was assessed how uncertainty affected the model's predictions. The model was then used to explore potential effects of future renewable energy development on population dynamics of golden eagles. This population model was not to



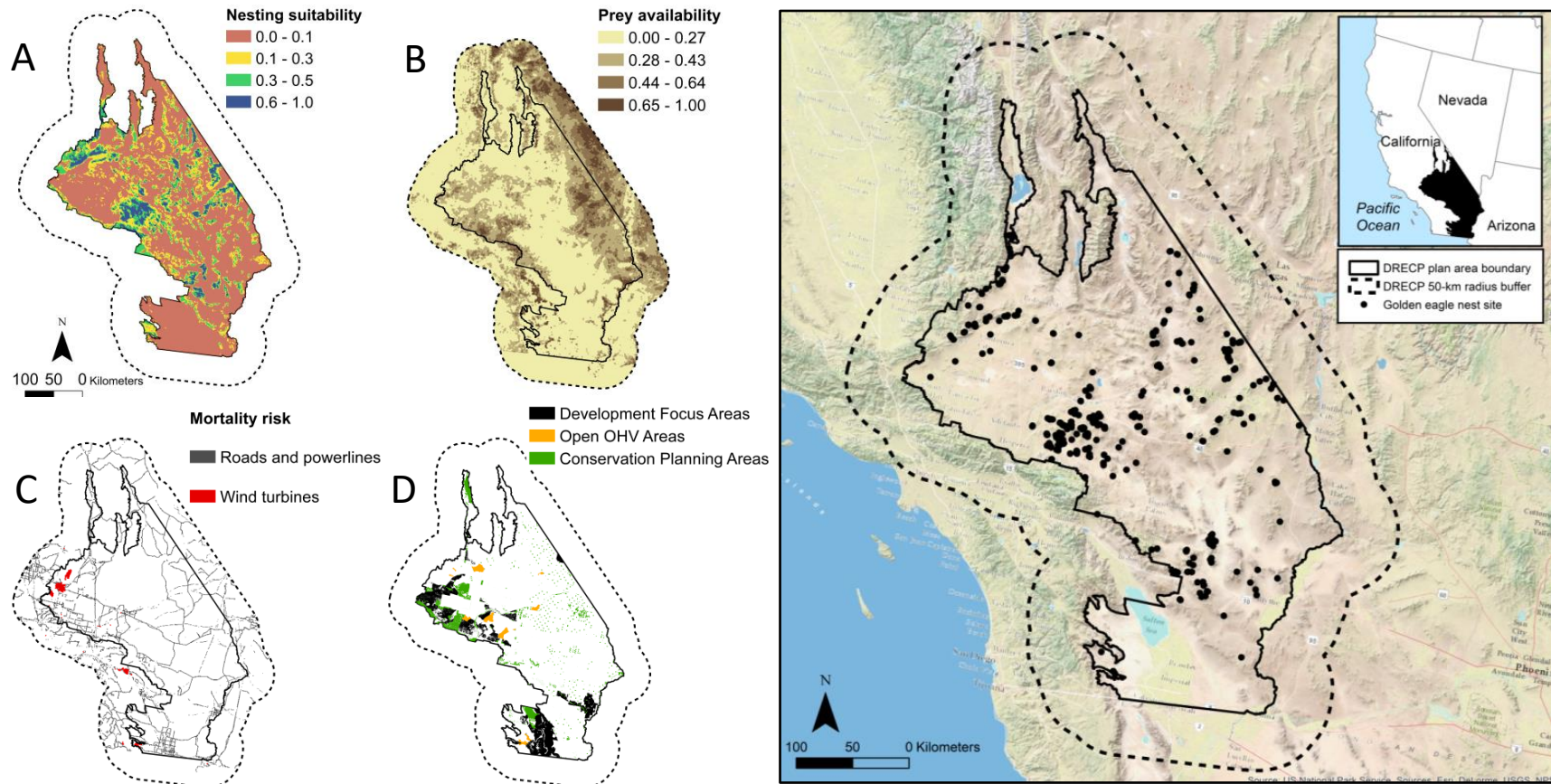
predict actual changes in the size of the target population, but rather to identify possible population responses to anticipated changes in land-use, and to assess possible conservation strategies by their relative effects on abundance and distribution of golden eagles. Specific objectives were to: 1) develop and document a spatially-explicit, individual-based simulation model for the local population of golden eagles in the DRECP region, 2) assess the performance of the model in capturing expected conditions of the population, 3) determine sensitivity of results to uncertain demographic parameters, and 4) use the model to explore possible demographic consequences of renewable energy development to golden eagles.

### **3.2 Model Development and Population Simulations**

The team modeled the local population of golden eagles within the DRECP (91,400 km<sup>2</sup>) and surrounding areas within a 50-km radius of the planning area boundary (total area = 192,444 km<sup>2</sup>; Figure 4). A 50-km radius was established around the plan area boundary to account for areas where resident eagles may encounter both risks and resources beyond those typically encountered within the plan area (Braham et al. 2015). This radius also approximated median natal dispersal distance of golden eagles (46.5 km; Millsap et al. 2014).

Availability of food and nesting sites are strong determinants of distribution, nesting density, and other life-history traits of golden eagles (Kochert et al. 2002, Watson 2010). Accordingly, the assessment included three interacting models developed for the study area: a nest habitat suitability model, a prey availability model, and a golden eagle population model. The nest habitat model estimated areas with suitable nesting conditions for golden eagles in the study area, and was developed from a species distribution model (SDM; Franklin 2010) that related known nesting locations with physiographic conditions associated with those sites. The prey availability model estimated the distribution of primary prey species found to occur in diets of golden eagles in the study area (Longshore et al. 2017), and was developed from line-transect density surveys of prey species conducted in 2014 and 2015. Spatial information from the nest habitat suitability and prey distribution models served as the landscapes for a spatially explicit, individual-based model of golden eagle population dynamics. The spatial distribution of nesting and food resources thus provided an environment within which movement, resource acquisition, reproduction, and survival could be simulated. The team initially developed a baseline population model reflecting current conditions, and then used this model to evaluate potential consequences of future renewable energy development to the local population. The model was also well suited to assess conservation actions proposed to offset probable impacts of future renewable energy projects (CEC 2014).

**Figure 4: Spatial Data Used to Inform the Golden Eagle Predictive Demographic Model for the DRECP Area, California**



Shown are the spatial data used to inform an individual-based, spatially explicit simulation model for golden eagles, including: (A) relative nesting habitat suitability, (B) estimated prey availability, (C) spatial mortality risk from wind turbines, high risk roads, and powerlines, and (D) locations of planned renewable energy development (Development Focal Areas), off-highway vehicle (OHV) use areas, and sites identified for conservation actions (Conservation Planning Areas; CBI 2014).

### 3.2.1 Nesting Habitat

A map of the spatial distribution of nesting areas was created for golden eagles using a SDM approach informed by 644 known nest locations identified from 1972 to 2012 (Figure 4). The sample of nest locations was compiled from multiple data sources, including the California Department of Fish and Wildlife Natural Diversity Database (CNDDDB version; accessed July 2013), records provided by Southern California Edison (SCE golden eagle Surveys, 2015, unpublished data), and nesting locations identified during helicopter surveys (Latta and Thelander 2013). Nest locations used in one or more years were checked for quality and accuracy, and duplications were removed prior to use.

Historical nests used by eagles in the study area tended to occur primarily along rocky cliffs, and to a lesser extent in large trees or other vertical structures (for example power poles) capable of supporting the weight of the bird's large stick nests (Brown 2014). A set of environmental covariates was calculated to capture environmental conditions hypothesized to be associated with the presence of nest locations using remote sensing data and a digital elevation model (DEM). Terrain features derived from the 30-meter resolution DEM included slope, surface roughness, elevation drop range, topographic position index, and solar insolation, while variables derived from remote sensing data included a quartz index, and albedo (see Inman et al. 2014 for details). Vegetation characteristics were initially considered throughout the modeling region, but subsequently removed these variables to ensure that nesting site potential was based predominantly on desert landscapes of the DRECP area. Rather, vegetation conditions were included in the development of the prey availability model.

Nesting suitability of golden eagles was estimated using a hierarchical Bayesian model conditional on latent processes of clustered sampling bias and spatial autocorrelation (Wikle 2003, Cressie et al. 2009). The team modeled the observation process at a 1-km spatial resolution to capture nesting suitability following a binomial distribution, and included process models for survey bias and spatial autocorrelation (Besag et al. 1991). A benefit of this approach was its ability to directly quantify uncertainty in the modeling process due to spatially correlated, or clumped, point data (Cressie et al. 2009), which was an inherent aspect of the data because many of the nest locations in the sample were alternate nests grouped within a smaller number of more widely dispersed breeding territories. In general, optimal SDMs should have good predictive abilities using relatively few predictor variables (such as they should be parsimonious).

To evaluate the predictive capability of the nest habitat model, the team randomly withheld 30% of the nest observations using a geographically weighted sampling approach that approximated a uniform spatial distribution. The randomly withheld subset of nests was used to evaluate the nest model using three complimentary measures: Area Under the Receiver-Operating Curve (AUC; Fielding and Bell 1997), Root Mean Square Error (RMSE) and Mean Cross Entropy (MXE). Despite the extensive use of AUC for evaluating SDM's (Franklin 2010), it may represent artifacts of species prevalence ratios, thereby providing an incomplete picture of model performance (Lobo et al. 2008). As a consequence, MXE was used, which has shown good potential for use with SDM-type approaches (Georgiou and Lindquist 2003).

### 3.2.2 Prey Availability

Recent studies of diets of golden eagles in the study area (Longshore et al. 2017) showed that the two most common prey items observed at used nests were black-tailed jackrabbits (*Lepus californicus*) and cottontail rabbits (*Sylvilagus* spp.). In a concurrent study, abundance data were collected for these two prey species and others during the breeding season (Jan – Jul) using nocturnal spotlight line-transect distance surveys conducted in 2014 and 2015 (Longshore et al. 2017). These survey data were used to estimate landscape density of rabbits in the study area. Detections of jackrabbits ( $n = 622$ ) and cottontail rabbits ( $n = 41$ ) from 182 survey occasions were analyzed using the Distance package in R (v 3.2.3, R Core Team 2015). Detections of prey species were analyzed using combinations of environmental covariates hypothesized to explain prey density. Specifically, covariates for terrain aspect, elevation, slope and topographic position were calculated using a 30-m DEM (Inman et al. 2014). Distance detection functions were developed to compare null models with no covariates to models including different combinations of topographic and vegetation covariates (normalized difference vegetation index) hypothesized to influence detection of prey species (Longshore et al. 2017). Distance data were binned at 25-m intervals (Buckland et al. 2005), and distance models were ranked using an information-theoretic method (AIC; Burnham and Anderson 2002, Buckland et al. 2005), where the model with the best support from the data was used to create a predictive density surface at a 1-km<sup>2</sup> scale.

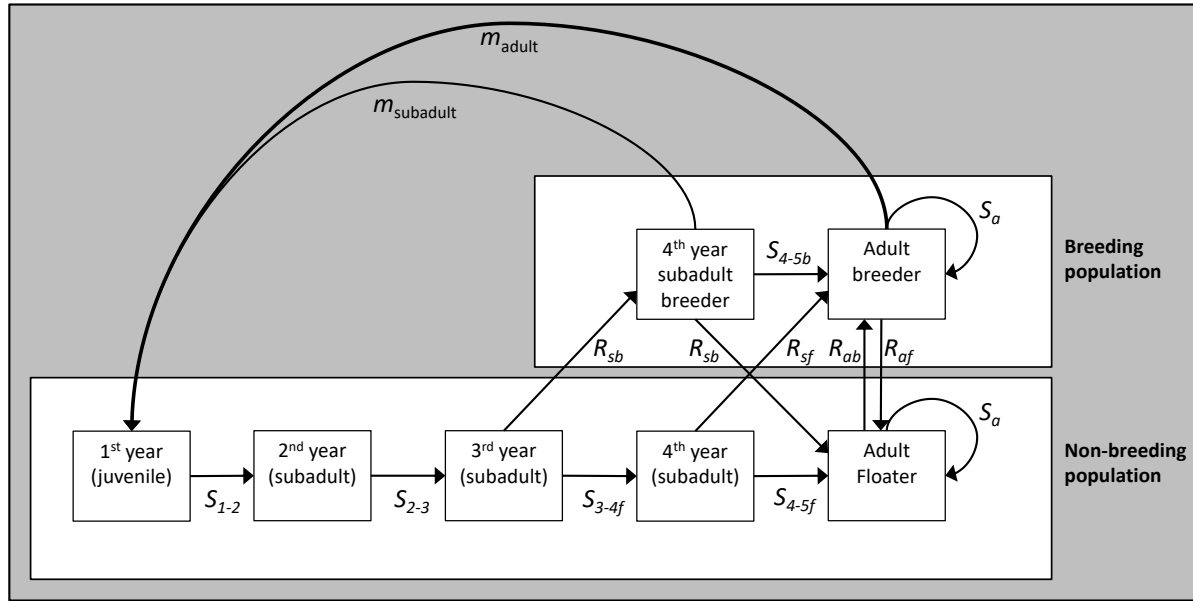
### 3.2.3 Population Simulation Model

The team used HexSim (Heinrichs et al. 2010, Schumaker et al. 2014) to construct a population simulation model for golden eagles. HexSim is a spatially-explicit, individual-based population modelling platform designed for simulating dynamic interactions between terrestrial wildlife and associated landscapes. The spatial grain and extent of the models can be set by users to any values appropriate for the study system, from local population level to a species' entire geographic range (Schumaker et al. 2014, Tuma et al. 2016). The baseline HexSim model integrated life-history and demographic traits of golden eagles with spatial data layers characterizing the distribution of nesting habitats, prey resources, and potential threats. The region available to individual eagles simulated in HexSim (Figure 4) consisted of 185,499 hexagonal cells, with each hexagon being 1-km<sup>2</sup> in area and 1,074 m in diameter. This resolution captured relevant details of landscape conditions at broad spatial scales while minimizing model run time. The nesting suitability and prey base maps, along with spatial data of mortality risks, determined movements, resource acquisition, and exposure to threats. This framework enabled the team to directly integrate empirical data on the spatial distribution and availability of nest sites and primary prey species into the demographic model, which ultimately determined fitness of simulated eagles as a consequence of each individual's ability to acquire these resources.

The approach to model development was similar to that used for assessments of critical habitat configurations for the federally threatened northern spotted owl (*Strix occidentalis caurina*; USFWS 2012, Schumaker et al. 2014). The population model represented only the female component of the golden eagle population because there was found little data on sexual variation in published estimates of demographic parameters. The population simulations used a stage-dependent demographic model that reflected different age-classes (first-year juveniles, 2 – 4 year-old sub-

adults, adults) and breeding states (breeders, non-breeders; Figure 5). The five age classes in the model allowed the team to examine age-related mortality effects on population size by simulating processes affecting key annual life-history events of individuals, including territory prospecting and establishment, foraging and resource acquisition, reproduction, dispersal, and survival (Figure 6). The parameter values used in the baseline HexSim model for each life-history event are provided in Appendix B.

**Figure 5: Life Cycle of the Simulated Population of Golden Eagles in the DRECP Area, California**

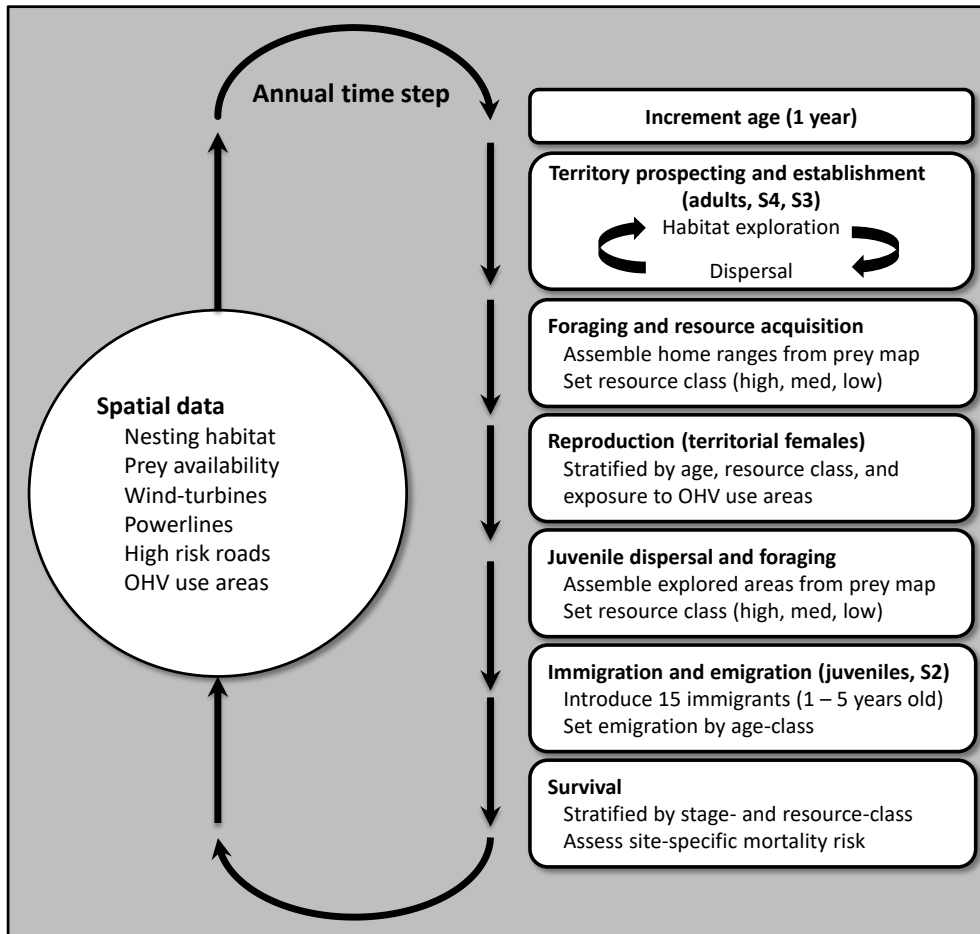


Boxes represent the different age- and stage-classes represented in an individual-based, spatially explicit simulation model, where  $S_i$  is the survival for age-class  $i$ ,  $m_i$  is fecundity (mean number of female young fledged per territorial female) for age-class  $i$ , and  $R_i$  is recruitment for age-class  $i$  between breeding and non-breeding segments of the population. Different stage classes are denoted as adult (a) or subadult (s) floaters (f) or breeders (b).

### 3.2.3.1 Starting Population Size and Territory Establishment

Simulations began with 500 individual female golden eagles being introduced at random locations across the study area. A large starting population ensured that individuals were well-distributed throughout the entire modeling region. The ages of individuals in the initial population were randomly distributed. Once model initialization was complete, each individual eagle was subjected to the annual event cycle shown in Figure 6. At the beginning of each annual time step, each surviving individual becomes a year older and advances to the next age class. Next, third- and fourth-year sub-adults and adults prospect for a breeding territory, which was informed by the nesting habitat model. This process required individuals to build non-overlapping breeding territories (i.e., defended areas) by exploring a sufficient number of adjacent hexagons in the nesting habitat suitability map.

**Figure 6: Modeling Sequence of an Individual-based, Spatially Explicit Simulation Model for Golden Eagles in the DRECP Area, California**



The quality of each hexagon ranged from 0.0 – 1.0 according to values of the nesting habitat map, and simulated eagles required a cumulative nesting habitat quality score of  $\geq 10$  before a territory could be established in an area for subsequent construction (Appendix B). A threshold value of 10 was used based on a visual assessment of hexagon scores surrounding actual nest locations used by golden eagles in the study area. The goal of territory construction was to acquire a cumulative target nesting habitat score of 40, which had the effect of increasing territory sizes, but only in the best quality areas. Prospecting eagles that were unable to achieve a nesting habitat score of 10 in one location were permitted to disperse between 50 and 100 km in an attempt to build a territory elsewhere. Prospecting adults that could not achieve their target nesting value in five prospecting-dispersal cycles in a single time-step transitioned to the non-territorial segment of the population (Figure 5). Prospecting subadults remained non-territorial floaters if they could not establish a territory within three prospecting-dispersal cycles in a time-step.

Once settled on a breeding territory, golden eagles exhibit strong site fidelity (Kochert et al. 2002, Watson 2010). Accordingly, the model assumed that once a simulated eagle acquired a breeding territory at age  $\geq 4$ , it would remain on or return to that same breeding territory on each subsequent

time step. Juveniles and second-year subadults do not prospect for territories in the model, but instead establish temporary home ranges in which to draw prey resources. This parameterization of territory prospecting and establishment resulted in density-dependent feedback on population growth by limiting availability of nesting sites and foraging areas (Brown and Watson 1964, Newton 1992).

#### 3.2.3.2 Foraging and Resource Acquisition

In the next step of the model, simulated eagles acquired food resources by establishing large, overlapping home ranges that were centered on territories and superimposed over the prey availability map. Home ranges were constructed using the prey availability map, where individual eagles attempted to acquire hexagons with the highest prey value scores until they either reached their stage-specific resource target value, or maximum allowable home range size (Appendix B). This resulted in large, irregularly shaped home ranges centered on smaller territories. Modeled home ranges approximated published estimates of space use by golden eagles in the study region (Braham et al. 2015, Poessel et al. 2016), and varied in size from 500 to 800 km<sup>2</sup>, and among stage classes, such that territorial adults used the smallest ranges and second- and third-year subadults used the largest (Appendix B). Home ranges could overlap among modeled eagles, which meant that they experienced competition for prey resources from other eagles. Access to resources within overlapping home ranges was prioritized based on territorial status and age class in the following order (from highest to lowest priority): territorial adults and fourth-year subadults, adult and fourth-year subadult floaters, third-year subadults, second-year subadults and juveniles.

All individual eagles were categorized into one of three resource classes (low, medium, high) based on the total amount of prey resources within their assembled home range (Appendix B). Resource classes influenced each individual's reproduction and survival. Relationships between food availability and reproduction and survival were approximated based on empirical studies of golden eagles and similar species (Steenhof et al. 1997, McIntyre and Schmidt 2012, Resano-Mayor et al. 2016). Each simulated eagle also had a resource target, which was used to determine how much prey resources individuals needed to be placed into the best resource class. The team approximated resource target values based on a visual assessment of prey values in hexagonal cells surrounding actual nest locations in the study area. Simulated eagles that acquired  $\geq 90\%$  of their prey resource target were placed into the high resource class, those that acquired  $< 40\%$  of their prey resource target were placed into the low resource class, and all others were placed into the medium resource class. This categorization of resource acquisition was used so that there were few individuals being placed into the high resource class with relatively higher reproduction and survival.

#### 3.2.3.3 Reproduction

The team modeled fecundity (i.e., number of young fledged per territorial female per year) to approximate published estimates from long-term field studies of golden eagles in California (0.345; Hunt 2002), southwestern Idaho (0.395; Steenhof et al. 1997, 2014), and southeastern Alaska (0.31; McIntyre and Schmidt 2012, also see Tack 2016). Published estimates were divided by two to obtain estimates of fecundity for these studies (assumes a 1:1 sex ratio). Annual reproduction for each territorial female was drawn from a Poisson distribution to determine clutch sizes of 0–3 young, such that clutch sizes were not equally likely and nesting events with three young were uncommon

(Kochert et al. 2002). The Poisson parameter value was subsequently multiplied by coefficients for an individual's age class (adults, fourth-year subadults), resource acquisition class (low, medium, high), and amount (%) of territory overlap with off-highway vehicle (OHV) recreation sites (Appendix B). For the age class coefficient, it was assumed that fourth-year subadults would establish territories less frequently and have lower reproductive rates (i.e., forgo reproduction more frequently) than older adults (Steenhof et al. 1983, Sánchez-Zapata et al. 2000). Eagles younger than four years old did not breed in the model (Steenhof et al. 1983, Ferrer et al. 2003, Katzner et al. 2006).

In Idaho, Steenhof et al. (2014) observed increased rates of nesting failure and reduced reproductive output at breeding territories exposed to increasing levels of OHV use. Based on these findings, it was assumed that modeled eagles whose breeding territories overlapped with designated OHV sites by  $\geq 85\%$  would fail to successfully produce young. The OHV areas ranged in size from  $<0.01$  to  $231 \text{ km}^2$  (mean =  $21.8 \text{ km}^2$ ), and were locations designated for open recreational use of OHVs (Figure 4; CBI 2014). A large (conservative) level of territory overlap was chosen to trigger OHV effects, but varied the overlap parameter systematically to determine its influence (see Methods: Model Assessment). The size and shape of simulated breeding territories varied among time-steps, so nesting eagles whose territories were spatially associated with OHV areas were not always disturbed at every time step. Reproductive output of golden eagles tends to be highly variable among years, perhaps due in part to annual fluctuations in weather and prey population (Steenhof et al. 1997, McIntyre and Schmidt 2012). This form of environmental (climatic) stochasticity was included in the model by multiplying values of expected reproduction by a single coefficient (range = 0 to 1) drawn randomly from a uniform distribution at each time-step. As a result, the model assumed both demographic (i.e., individual) and environmental stochasticity in population growth.

#### 3.2.3.4 Dispersal Movements

After reproduction, juveniles initiated dispersal from their natal territories. Dispersing juveniles moved in any direction from 90–175 km, and their movements were informed by the prey availability map (Appendix B). Dispersers moved with high spatial autocorrelation (i.e., fairly linear paths), but increased their turning frequency as necessary to avoid areas with very low prey availability, and to move increasingly towards areas with relatively greater prey. Once simulated juveniles made initial dispersal movements, they established a temporary home range up to  $800 \text{ km}^2$  in size in which to draw prey resources. As with other age classes, juveniles were assigned to a resource class based on the amount of prey resources calculated within their home range. Recent studies show that resident golden eagles in the study area have wide-ranging movements that extended to higher elevations beyond the DRECP boundary, especially in hot summer months (Braham et al. 2015). In addition, eagles from beyond the study area may migrate to the area in winter (George et al. 2014). To simulate movement of golden eagles into and out of the study area, the team assigned an annual emigration probability of 0.12 and 0.10 for simulated juvenile and subadult eagles, respectively, and introduced 15 pre-adult immigrants of random age to the population each year (Appendix B).



### 3.2.3.5 Survival

Annual survival of simulated eagles was based on empirical, age-specific estimates obtained from analyses of band-recovery data collected between 1968 and 2014 in the western U.S. (USFWS 2016). Baseline survival rates of individuals varied with age and resource class (Appendix B). Additional mortality (5–10%) was imposed on individuals that occupied home ranges in the low resource class (i.e., individuals with prey acquisition scores < 40% of target values), and increased survival by 3–4% for individuals that occupied home ranges in the high resource class (scores  $\geq$  90% of target values). Survival of individuals was also influenced by sources of mortality within home ranges (i.e., collisions with wind-turbines, electrocution, vehicle collisions). This parameterization resulted in stage-specific survival rates that varied spatially according to resource availability and site-specific sources of mortality. The team also reduced the annual survival rate of senescent individuals (eagles >20 years old) to 0.50, which still allowed a few simulated eagles (<0.05% of the total population) to attain ages of between 20 and approximately 35 years-old (Kochert et al. 2002).

The population model was informed by several publically available spatial data layers developed for the DRECP, including the locations of current powerlines, wind turbines, and roads and highways (CEC 2014, CBI 2014). These data were used to develop a site-specific risk map of mortality. The risk map of the current distribution of potential threats was included in the baseline population model described above, which increased mortality of simulated eagles by subtracting between 0.0001 (collisions with vehicles on high-risk roads) and 0.0026 (powerline electrocutions and collisions with wind turbines) from baseline survival rates (Appendix B). The spatial mortality risk map characterized the cumulative effects of select anthropogenic stressors, which reflected only a portion of annual mortality sources for golden eagles (Hunt 2002, USFWS 2016). As a result, baseline survival rates were scaled appropriately to better approximate published estimates, and to capture other sources of natural (e.g., disease) and anthropogenic (e.g., lead exposure) mortality not specifically included in the model.

### 3.2.4 Potential Effects of Energy Development

The team simulated the potential influence of anticipated changes in land-use on the local population of golden eagles by introducing Development Focal Areas (DFAs; Figure 4). The DFAs ranged in size from 0.001 to 2,882 km<sup>2</sup> (mean = 3.93 km<sup>2</sup>), and were locations where planned renewable energy generation and transmission projects could be streamlined for approval and construction (CBI 2014, CEC 2014). These areas do not necessarily represent actual project sites, but were useful to estimate the land area where fatality rates and foraging habitats of golden eagles are most likely to be affected by future renewable energy projects and associated infrastructure.

Development Focal Areas were added to the baseline mortality risk map by increasing risk of mortality in these areas. The team used estimated turbine blade-strike collision probabilities calculated for golden eagles ( $0.0037 \pm 0.0015$  [SD]) by New et al. (2015) to approximate increases in fatalities within DFAs. The team also simulated the potential for degradation of foraging habitats in DFAs by subtracting 25% of baseline hexagon scores of the underlying prey availability map. This resulted in a new set of maps of mortality risk and prey availability, with the new DFAs in place. Four risk scenarios were developed using the new disturbance and resource maps, each representing a different assumption about fatality rates, or habitat degradation, within future DFAs,

including: (1) an increase in mortality risk by 0.0027 with no effect on prey availability (low effect), (2) an increase in mortality risk by 0.0047 with a 25% reduction in prey availability (moderate effect), (3) an increase in mortality risk by 0.0077 with a 25% reduction in prey availability (severe effect), and (4) mortality risk and habitat disturbance had moderate effects in DFAs as specified above, but coupled with a 99% reduction in the baseline risk of mortality from collisions and electrocution within Conservation Planning Areas (moderate effect with conservation). Conservation Planning Areas (Figure 4D) were areas specified for conservation actions to offset the potential negative impacts of development (CBI 2014, CEC 2014). All mapping was completed in ArcGIS 10.1.

### 3.2.5 Simulations and Model Assessment

Primary results were calculated from 10 replicate simulations of 500 time-steps each. Data other than population size used to assess the baseline population model were gathered from time steps 150 – 500, well after the population had reached a stable age-distribution. For disturbance scenarios, effects were introduced into the baseline model at time step 200, and population response was observed for the subsequent 300 time steps. These simulation times were not used to project population dynamics of golden eagles into the distant future, but rather to allow the models adequate time to reach steady state pre- and post-disturbance (Schumaker et al. 2014, Tuma et al. 2016), and to evaluate the relative population responses among different development scenarios. The team analyzed future risk scenarios by comparing mean population size over 50 time steps between pre- and post-disturbance. Here, the team arbitrarily selected time steps 149 – 199 and 450 – 500 for the pre- and post-disturbance periods, respectively, which were periods well beyond the asymptote for the population growth curve prior to, and following, disturbance introductions. Analysis of variance (ANOVA) was used to compare pre- and post-disturbance population sizes.

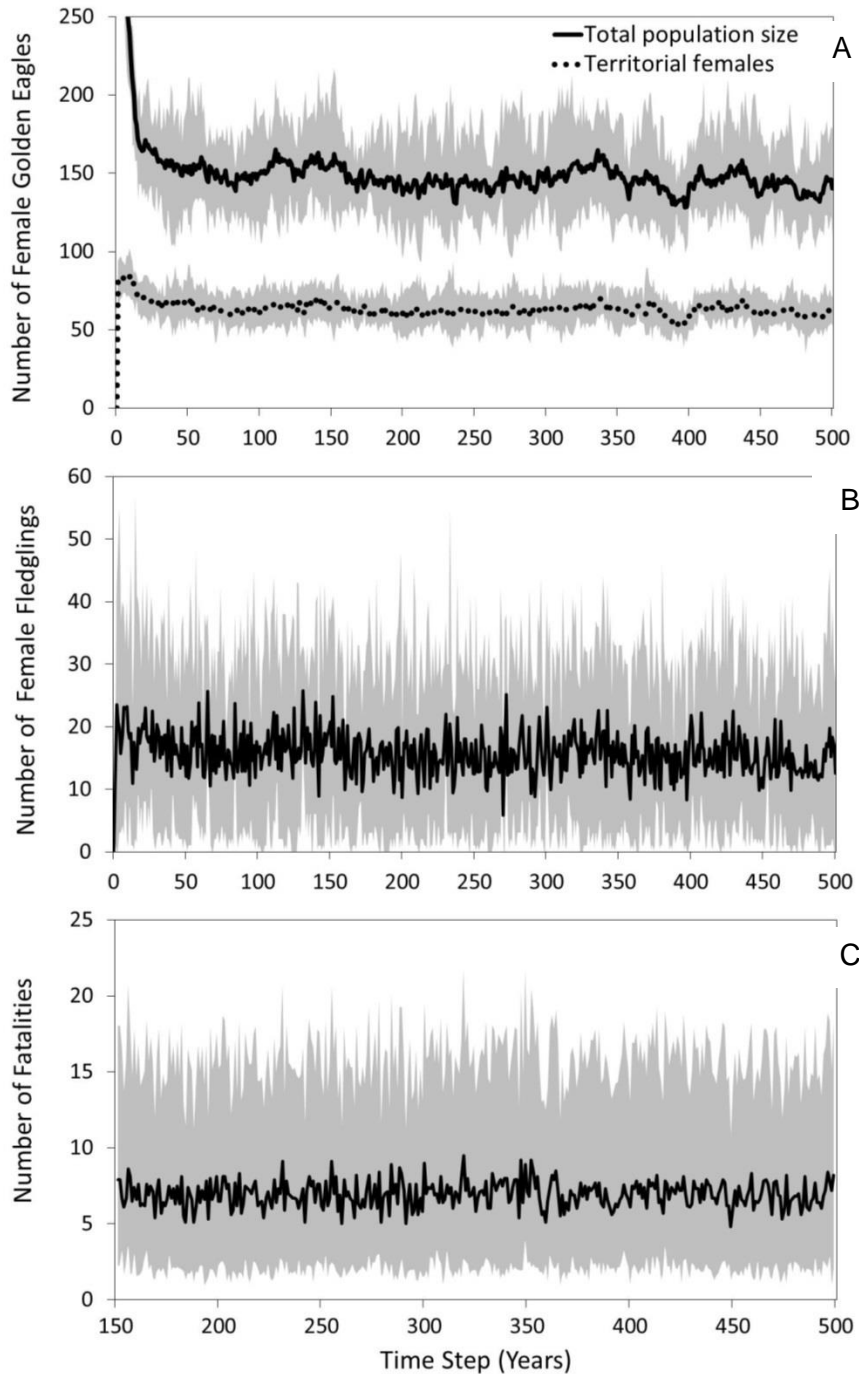
The team parameterized the baseline population model using a limited amount of empirical data. As a consequence, there were considerable uncertainties about model parameters that required us to make assumptions about demographic rates, resource acquisition, and the influence of anthropogenic stressors. It was determined how these assumptions could have influenced results in two ways. First, the general performance of the model was assessed by comparing estimates of population size and associated demographic parameters derived from simulated data to existing field data. Second, a sensitivity analysis approach (Marcot et al. 2015) was used to help identify the influence of uncertain model parameters or demographic rates that are difficult to measure in actual eagle populations. Specifically, the team estimated how incremental changes in five demographic parameters (adult survival, pre-adult survival, fecundity, emigration, immigration) affected population trajectories. The team also examined sensitivity of the model to parameter values used to inform territory size, stage-based resource acquisition rates, and effects of OHV disturbance. Input parameters were adjusted by  $\pm 10\%$  by multiplying baseline values by 1.1 and 0.9, respectively. The team calculated departure from the baseline model as the percent change in median population size, estimated from 10 replicates of each proportional change scenario. The team also developed a model without emigration and immigration to determine the influence of these parameters.

### 3.3 Simulation Results and Model Assessment

Replicates of the baseline simulation model produced a mean steady-state population size of approximately 145 female golden eagles (Figure 7A). Modeled population size was somewhat greater than a recent estimate from aerial surveys of golden eagles in the DRECP area (George et al. 2014), but the range of variability in population size over time was well within the margin of error reported by that study (Table 2). Mean number of occupied territories (i.e., territorial females) ranged from 33 to 94 (mean = 62.2 territories; Table 1, Figure 7A), which was similar to a field-based estimate ( $n = 74$  used nests; Latta and Thelander 2013). Simulated values of average fecundity and age-specific survival rates were all close to point estimates from studies conducted in the western U.S. (Table 1). Collisions with wind-turbines at existing wind energy facilities, collisions with vehicles, and electrocutions on power poles accounted for 20% of total annual mortality of simulated eagles (mean = 7.0 deaths per year, SD = 2.8; Table 1, Figure 7C), which approximated observed data on causes of death in a sample of 97 golden eagles tracked with satellite telemetry in the western U.S. (USFWS 2016:13–14). Territories constructed by simulated eagles ranged from 19 to 50 km<sup>2</sup> (mean = 44.9 km<sup>2</sup>). The size of home ranges varied among age-class and population segments, such that territorial adults used the smallest ranges and pre-adults (i.e., juvenile and subadults) used the largest. The size of modeled territories and home ranges tended to be larger than mean estimates from observed data (Table 1), but was within the wide range of estimates of individual eagles monitored with telemetry in the region (Braham et al. 2015).

Results of the sensitivity analysis (Table 2) showed that incremental changes in adult survival resulted in the greatest proportional change to total population size; a 10% decrease in baseline values of survival led to a 43% decrease in median total population size, whereas a 10% increase led to a 110% increase in median total population size. The analyses also showed that proportional decreases and increases in pre-adult survival (–31%, 44%) and fecundity (–23%, 22%) had substantial effects on total population size. The population model was also sensitive to changes in immigration and emigration, and values used to determine resource acquisition (Table 2). Proportional changes in parameterization of territory size and OHV disturbances had relatively little influence on model output (<5%). Models that assumed a closed population (no immigration or emigration) went to zero individuals during time-steps 150 – 250 under all simulations, indicating a heavy dependence on immigration to maintain numbers of breeding eagles in the landscape.

**Figure 7: Output from the Stable, Baseline Population Simulation Model for Golden Eagles in the DRECP Area, California**



Model output shown includes (A) total population size and number of territorial females, (B) number of female fledglings produced, and (C) number of fatalities from collisions with wind-turbines, powerline electrocutions, or collisions with vehicles during time-steps 150 – 500. Black lines show median values from 10 replicate simulations, each conducted over 500 time-steps (years); shaded areas indicate maximum and minimum values (A, B), or 95% confidence intervals (C).

**Table 1: Mean Values of Demographic Parameters Obtained from the Stable, Baseline Demographic Model for Golden Eagles in the DRECP Area, California, as Compared to Observed Values from Local Field Studies**

Parameter	Simulated Data		Observed Data <sup>a</sup>		
	Mean	SD	Value	95% CI	Source
Population size (number of female golden eagles)					
Total population size	145.0	20.4	67.5	20 – 170	A
Occupied territories (no. territorial females)	62.2	8.1	74.0	—	B
Territory density (occupied territories per 1,000 km <sup>2</sup> )	6.8	1.1	8.1	—	B
Juveniles	15.2	10.0	39.0	—	B
Subadults (2nd - 4th year)	39.7	10.7	—	—	
Floaters (non-territorial adults and 4th year subadults)	27.4	7.8	—	—	
Fecundity (mean number of young per territorial female)	0.34	0.21	0.35	0.105 – 0.705	C
Survival					
Juvenile survival	0.76	0.19	0.70	0.66 – 0.74	D
2nd year survival	0.78	0.20	0.77	0.73 – 0.81	D
3rd year survival	0.85	0.17	0.84	0.79 – 0.88	D
4th year survival	0.85	0.14	0.87	0.84 – 0.89	D
Adult survival	0.87	0.04	0.87	0.84 – 0.89	D
Cause of death					
Collisions and electrocution	0.20	0.09	0.19	—	E
Other anthropogenic and natural sources	0.80	0.11	0.81	—	E

## Movement and space use

Territory size (km <sup>2</sup> )	44.9	7.6	16.1	6.3 – 25.9	F
Adult home range size (km <sup>2</sup> )	489.4	59.6	307.8	133.7 – 480.5	F
Pre-adult home range size (2nd to 4th year eagles; km <sup>2</sup> )	665.0	121.8	307.8	133.7 – 480.5	F
Juvenile dispersal distance (km <sup>2</sup> )	134.2	25.4	151.0	74.7 – 227.5	G
Population growth rate ( $\lambda$ )	1.003	0.082	—	—	

<sup>a</sup>Simulated values were calculated from 10 replicates of the last 350 years of 500-year simulations. Key to observed data sources: (A) estimated from aerial line-transect surveys conducted in the DRECP area in 2012 (George et al. 2014). Published estimates were divided by two to get total abundance of females, assuming a 1:1 sex ratio; (B) estimated from helicopter survey of nests used by golden eagles in the DRECP area in 2012 (Latta and Thelander 2013); (C) estimated from a Bayesian gamma regression model with field-based measures of productivity from five long-term studies in the western U.S. (Tack 2016); estimates were divided by two to get fecundity values; (D) estimated from band-recovery data collected in the western U.S. from 1968 to 2013 (USFWS 2016); (E) estimated from fatalities of satellite-tagged golden eagles in the western U.S. (USFWS 2016; proportions recalculated from Table 8); (F) estimated from mean monthly convex hull home ranges from eight golden eagles marked with GPS-GSM transmitters (Braham et al. 2015); (G) estimated from 63 juvenile golden eagles marked with satellite transmitters in the southwestern U.S. (Murphy et al. 2017).

**Table 2: Sensitivity of the Stable, Baseline Demographic Model for Golden Eagles in the DRECP Area, California, to Incremental Changes in Uncertain Model Parameters**

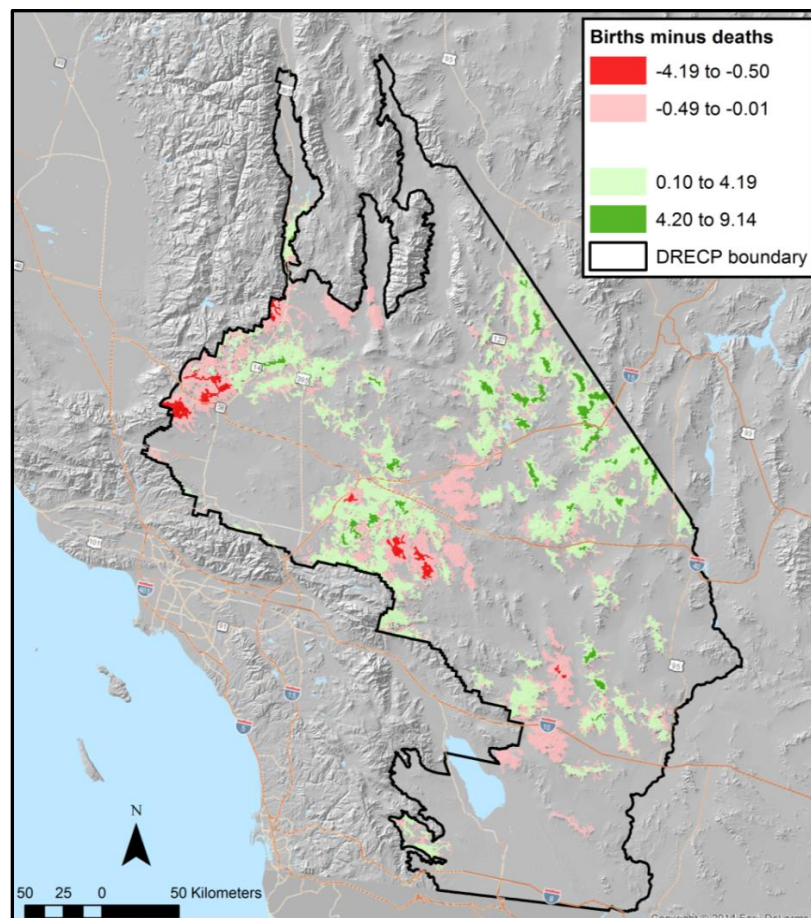
Parameter	Median Population Size <sup>a</sup>	SD	Percent Change From Baseline Model
Adult survival			
10% increase	300	32.1	110%
10% decrease	81	12.5	-43%
Pre-adult survival			
10% increase	206	29.6	44%
10% decrease	99	24.3	-31%
Fecundity			
10% increase	175	21.4	22%
10% decrease	110	20.0	-23%
Immigration			
10% increase	175	21.2	22%
10% decrease	105	18.3	-27%
Emigration			
10% increase	124	17.5	-13%
10% decrease	166	27.1	16%
Prey resource acquisition			
20% increase (prey rich)	166	23.8	16%
20% decrease (prey poor)	113	15.5	-21%
Territory size			
10% increase	144	19.1	1%
10% decrease	138	19.2	-3%
OHV disturbance			
Inactive (no disturbance)	146	21.5	2%
20% greater impact	136	21.5	-5%

<sup>a</sup>Model sensitivity was expressed as percent change in the size of the simulated population relative to the stable baseline population model when uncertain model parameters were proportionally increased or decreased by 10%. Median population size estimated from the baseline model was 143.0 ± 20.4 (SD) female golden eagles.

### 3.3.1 Emergent Population Dynamics

The team observed variation in the size, productivity, and age structure of the simulated population over time, which can be attributed to dynamics emerging from interactions among the demographic and environmental processes included in the model. Size, distribution, location, and annual occupancy rates of breeding territories emerged from spatial and temporal variation in availability of suitable nesting habitats and prey resources. Distribution of food resources changed over time following use and replenishment of prey resource values at hexagons used by foraging individuals among time steps. Resource acquisition was another emergent property of the model that varied with an eagle's location, territorial status, age class, home-range size, and competition with other simulated eagles. Spatial output of the baseline model included the predicted landscape distribution of high versus low quality breeding sites, as determined by breeding territories with the greatest reproductive output and fewest deaths over 150 years of simulation (Figure 8).

**Figure 8: Predicted Distribution of Long-term Productivity and Mortality in Breeding Ranges of Golden Eagles in the DRECP Area, California**



Shown is the mean number of births minus deaths per 1-km<sup>2</sup> within home ranges established by simulated eagles during 150 time-steps (years) and 10 replicate simulations of the stable, baseline population model. Source habitats appear in green, sink habitats appear in red.



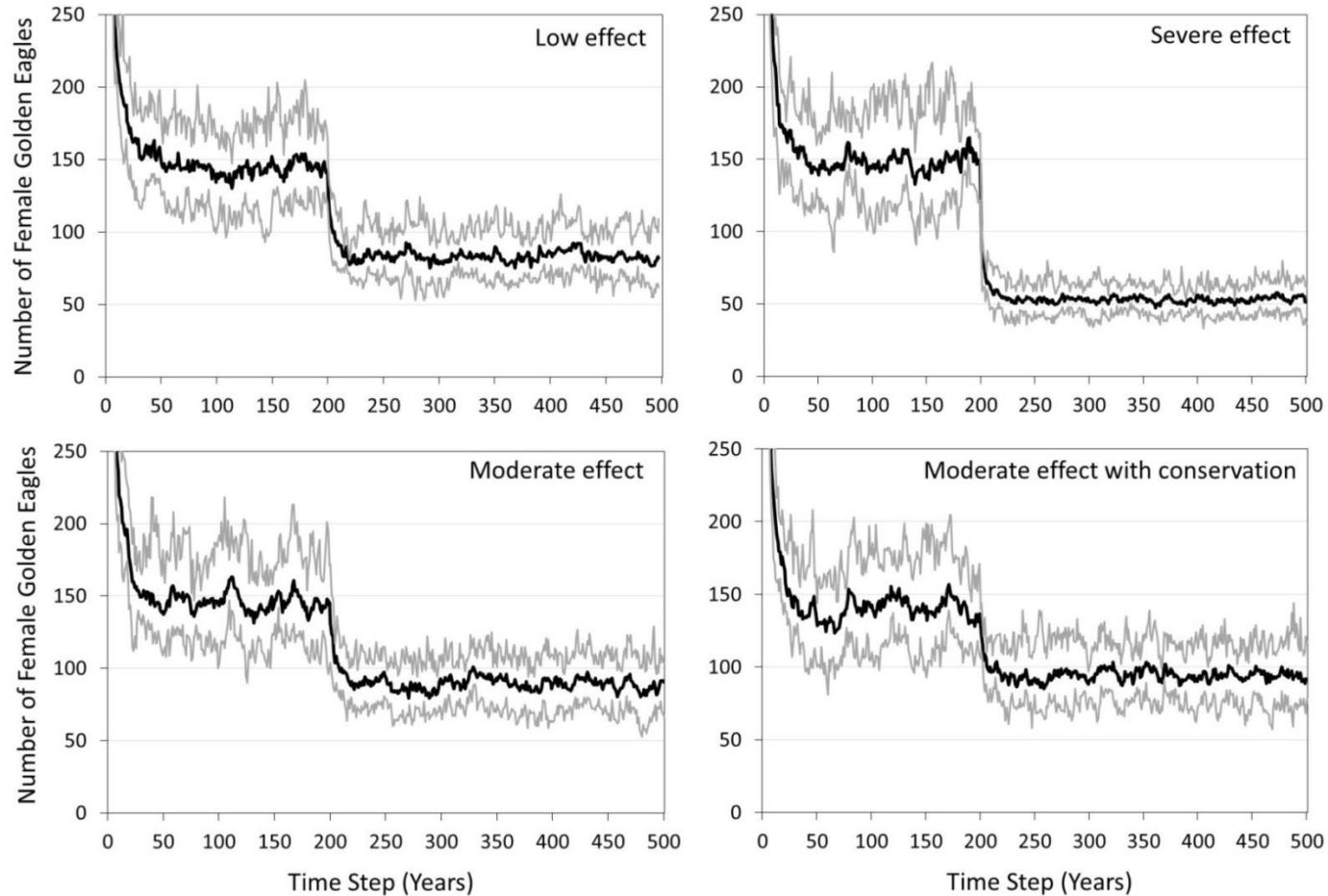
### 3.3.2 Potential Effects of Energy Development

All scenarios representing different levels of risk of future renewable energy development resulted in a significant population decline (Table 3, Figure 9). The worst-case scenario, which assumed that fatality rates of simulated eagles would increase in DFAs by 0.0077 with a concurrent 25% reduction in prey numbers, caused the most precipitous and significant decline (66% decline in post-disturbance population size; Figure 9). Contrary to expectations, a scenario with a relatively low increase in site-specific fatality (0.0027) and no effects on prey availability resulted in a similar decline in population size relative to a scenario with a moderate increase in fatality (0.0047) plus a 25% reduction in prey availability (Table 3). This result occurred in the model because ranging behavior of simulated eagles was largely determined by prey availability, so that when prey values declined in disturbed areas (i.e., simulating degradation of foraging habitats), so did the use of these areas by foraging eagles. A scenario with moderate effects of development, but coupled with conservation actions (i.e., a 99% reduction in mortality risk in Planned Conservation Areas), resulted in the smallest population decline of the four scenarios considered, but the decline was still notable (33% decline in post-disturbance population size). Mean post-disturbance population size under the scenario with conservation actions was significantly greater than a similar scenario without conservation actions ( $F_{1, 1019}$ ,  $P < 0.001$ ; Table 3).

## 3.4. Synthesis and Conclusions

The team developed, documented, and assessed a spatially-explicit, individual-based simulation model for a local population of golden eagles exposed to rapid increases in renewable energy development. This study provided initial insights into the effectiveness of using such models to identify possible population responses of golden eagles to renewable energy development relative to other sources of anthropogenic (or natural) mortality. The simulated population of golden eagles was found to have behavior consistent with life-history traits and population demography of natural populations, especially with respect to studies conducted on breeding populations in the desert regions of the American Southwest. The team showed that complex interactions between highly mobile individuals, the distribution of their resources, and site-specific changes in land-use could be effectively represented within a virtual modeling environment. Simulated increases in the future occurrence and distribution of anthropogenic stressors resulted in alternate population trajectories for golden eagles. The simulation model developed should be a particularly useful tool for researchers and land managers wanting to explore how proposed site-specific management actions may affect a local breeding population of eagles, or for evaluating spatial conservation options.

**Figure 9: Predicted Population Response of Golden Eagles in the DRECP Area, California, to Different Risk Scenarios Associated with Planned Energy Development**



Risk scenarios included an increase in mortality of 0.0027 in Development Focal Areas (DFAs) with no effect on prey availability (low effect), an increase in mortality risk of 0.0047 in DFAs with a 25% reduction in prey availability (moderate effect), an increase in mortality risk of 0.0077 in DFAs with a 25% reduction in prey availability (severe effect), and the moderate effect scenario coupled with a 99% reduction in mortality risk in Planned Conservation Areas (moderate effect with conservation). Black lines show median values from 10 replicate simulations, each conducted over 500 time-steps (years); grey lines indicate maximum and minimum values.

**Table 3: Estimates of Mean Pre- and Post-disturbance Population Sizes from Replicate Simulations of Different Hypothesized Effects of Future Renewable Energy Development on Golden Eagles in the DRECP Area, California**

		Pre-disturbance			Post-disturbance			ANOVA <sup>b</sup>	
		Population Size			Population Size				
Potential Maximum									
Risk Scenario <sup>a</sup>	Fatality Rate	Mean	SD	Min – Max	Mean	SD	Min – Max	$F_{1,1019}$	$P$
Low	0.0054	145.5	18.4	110 – 205	83.2	12.1	53 – 124	4090.4	<0.001
Moderate	0.0074	146.0	20.5	96 – 213	85.7	11.4	60 – 122	3365.4	<0.001
Severe	0.0104	149.6	21.5	95 – 217	53.0	7.3	35 – 80	9223.2	<0.001
Moderate with conservation	0.0074	140.4	20.9	93 – 205	93.1	14.8	63 – 189	1738.8	<0.001

<sup>a</sup>Pre- and post-disturbance means were calculated from time steps 149 – 199 and 450 – 500, respectively, over 10 replicate simulations of each risk scenario. Risk scenarios included an increase in mortality risk of 0.0027 above baseline levels in Development Focal Areas (DFAs) and no effect on prey availability (low effect), an increase in mortality risk of 0.0047 above baseline levels and a 25% reduction in prey availability within DFAs (moderate effect), an increase in mortality risk of 0.0077 above baseline levels and a 25% reduction in prey availability within DFAs (severe effect), and an moderate increase in mortality risk (0.0047) and a 25% reduction in prey availability within DFAs, but coupled with a 99% reduction in mortality risk within Planned Conservation Areas (moderate effect with conservation).

<sup>b</sup>Analysis of variance (ANOVA) comparison of pre- and post-disturbance population size means.

Recently, USFWS (2016) compiled information on population size and trend of golden eagles, generated estimates of recent survival and fecundity rates, and used these data in matrix population models to forecast future population trends and the ability of golden eagles in the western U.S. to withstand additional mortality. Their analysis suggested that any increases in mortality to current populations will either exacerbate the potential for future declines, or steepen the rate of any current declines (USFWS 2016:25). Results from the population simulation model developed here were consistent with these findings, as additional mortality associated with future disturbance scenarios led to a significant decline in population size. A limitation of traditional matrix population models is that they do not readily accommodate threats that act on individuals at varying spatial scales, so they cannot easily identify the importance of specific landscape locations in sustaining populations (Munns 2006, Schumaker et al. 2014). This study demonstrated how such insights can be gained from individual-based, spatially explicit population models. Each simulated eagle in the model possessed traits that varied in time and space relative to age, resource availability, disturbances, or territorial status. Emergent population dynamics from the simulation model illustrated how survival, reproduction, and population trends of golden eagles depended on complex interactions among spatial, demographic, and environmental sources of variation. This analytical framework contrasted sharply with traditional projection matrix models in which such interactions must be parameterized and stipulated in advance, and then used to guide the outcome of abundance and distribution of a study population.

Achieving correspondence between output of the population model and observed field data was a critical step in validating the forecasting capabilities of the model. Population size and distribution, breeding parameters, mortality processes, and movement behaviors of the simulated population were generally consistent with empirical field studies of golden eagles. These simulations produced a steady-state mean population size in the study area of 145 females (290 individuals total, assuming a 1:1 sex ratio), which was somewhat larger than an estimate (135 individual females) from aerial surveys conducted in the study area by George et al. (2014), but well within the 95% confidence interval of their estimate (41 to 340 female eagles, assuming a 1:1 sex ratio). As noted by George et al. (2014:2), however, the precision of their estimate of population size was poor, and it was possible that prey and eagle numbers were depressed in the study area during their surveys because of severe drought conditions. Additional surveys are needed to determine population size with greater precision under a broader range of environmental conditions. Such information could be used to validate and refine estimates of population size in the simulation model, thereby increasing its predictive capabilities.

Based on the sensitivity analysis, changes in adult survival had the greatest proportional influence on relative population size. This finding was similar to that of Whitfield et al. (2004) and Tack (2016), who used matrix models to show that even small changes in adult survival of golden eagles had disproportionately strong effects on population growth rate ( $\lambda$ ). Collectively, these findings suggest that conservation efforts focused on improving adult survival should make disproportional contributions to maintaining relatively stable population trajectories. Incremental changes in pre-adult (juvenile and subadult) survival had pronounced effects on

local population size, and immigration and emigration of non-breeding individuals also played a large role in stabilizing localized population trends. Thus, while these results are consistent with other studies in that adult survival should be the most important demographic parameter for the population dynamics of golden eagles, an exclusive focus on this parameter in a conservation context overlooks the potentially strong controlling influences that pre-adult survival and dispersal movements may have in stabilizing local breeding populations. In the simulations, immigration from outside the study region and natal dispersal within the study area acted jointly to sustain a local breeding population that would otherwise decline to extinction. This finding illustrated how the local population could appear stable only because of sustained immigration from outside of the DRECP area, which emphasizes the importance of a broad-scale perspective to conservation and research of golden eagles (also see Katzner et al. 2016). Pre-adult golden eagles pass through a highly nomadic phase of dispersal in which specific yet disparate areas may be intensively used (Soutullo et al. 2006, Poessel et al. 2016, Murphy et al. 2017). These findings show that identifying these areas and implementing site-specific conservation measures aimed at mitigating mortality sources could make disproportionate contributions to long-term stability of local and regional populations. In practice, this means allowing surrounding areas to produce dispersing eagles while minimizing disturbance and mortality sources at the most productive breeding sites.

Decreasing mean reproductive output also had a disproportionately large effect on relative size and distribution of the simulated population of eagles. This finding supports management strategies that work towards mitigating low productivity caused by decreases of main prey species, or by reducing human disturbances in breeding and foraging sites to help offset increases in fatality rates elsewhere in the landscape (CEC 2014). The parameterization of disturbance effects to nesting golden eagles caused by OHVs had little effect on population size and distribution. Other studies suggest that OHVs can have substantial negative effects on nesting success of golden eagles via increased human disturbance and subsequent nest abandonment (Steenhof et al. 2014). Although the team did not observe any pronounced effects of OHVs in the model, it is noted that the study only addressed possible interactions at designated OHV sites, whereas actual use of OHVs may be more widespread (e.g., remote trails near nesting sites). As with other uncertainties of the model, the threat of OHV disturbance may be greater than recognized and future work could build upon the model to examine specific hypotheses about disturbances caused by OHV use.

#### **3.4.1 Potential Effects of Energy Development**

Future renewable energy development under the DRECP includes the construction of wind-turbines, solar collection fields, power lines, and roads, which are anticipated to result in the loss of foraging habitats, breeding territories, and individual golden eagles via increased fatality rates (Brown 2014, Pagel et al. 2013, CEC 2014). The case study presented here is among the first to investigate how increases in renewable energy development could interact with other limiting factors to affect population dynamics of golden eagles, and how conservation planning areas might be most effectively placed to offset anticipated negative impacts. The team found that even small increases in mortality risk to simulated eagles within planned development sites had negative consequences for future population trajectories. This result was not particularly

surprising, especially given the juxtaposition of highly suitable nesting habitats and prey resources (Fig 4A, B) relative to areas targeted for future development of renewable energy infrastructure (Fig 4D). In the simulation model, this spatial pattern created a dynamic in which territorial eagles, in particular, suffered increased mortality as they encountered emergent risks from newly constructed powerlines, wind turbines, and roads in established territories and home ranges. Given that the population model was especially sensitive to relatively small changes in pre-adult and adult survival, even small increases in mortality of these stages led to a disproportionately large and negative impact on the future number of breeding females in the landscape.

The population model developed here provided a broadly applicable conceptual framework within which to explore how relative population size and distribution of both breeding and non-breeding golden eagles could be affected by site-specific sources of mortality associated with current and future renewable energy projects. A small and relatively simplistic set of risk scenarios was used to demonstrate the ecological applications of the modeling framework in a conservation planning context. A more detailed analysis would have included a wider range of potential land-use effects on foraging habitats and prey populations, or effectiveness of specific mitigation actions (e.g., seasonal curtailment of wind turbines, power pole retrofitting to reduce electrocutions) in offsetting anticipated increases in fatality rates in DFAs. Nonetheless, even in the low-risk development scenario, the DRECP failed to meet its target conservation goal of a stable or increasing breeding population of golden eagles. This result suggests that rapid management actions may be required to meet established conservation goals of the DRECP.

#### 3.4.1.1 Effectiveness of Proposed Conservation Actions

Conservation actions that reduce the impacts of human-caused mortality to golden eagles will most likely be site specific. Proposed management options considered for conservation of golden eagles in the DRECP area include: (1) seasonal curtailment of wind turbines to reduce blade-strike collisions, (2) power pole retrofitting and use of raptor-safe new power poles to reduce the risk of electrocutions, (3) clearing high risk highways and roads of carcasses to reduce frequency of vehicle collisions with eagles feeding on carrion, and (4) habitat restoration in disturbed areas (CEC 2014). The cumulative benefit of these proposed conservation actions to golden eagles were explored by reducing site-specific mortality rates in designated Conservation Planning Areas. A comparison of models with and without conservation actions showed that site-specific reductions in mortality risk helped to offset the negative impacts to the population caused by an increased fatality rate in newly developed areas. It remains unclear whether such reductions in localized fatality rates are within the reach of management, but the analyses presented here clearly illustrated the relative benefits of possible site-specific conservation actions.

The effects of wind turbines on birds, and possible mitigation measures, have been studied increasingly in recent years (Marques et al. 2014). Currently, little is known regarding the numbers of golden eagles that are killed each year by collisions with existing wind turbines in the study region (Pagel et al. 2013, Lovich 2015). The DRECP calls for up to 20,000 megawatts of renewable energy in the plan area (CEC 2014), which requires construction of new transmission

lines to carry that energy. Utility structures such as power poles and powerlines can pose a major threat to eagles through electrocutions and collisions (Lehman et al. 2007, Dwyer et al. 2014). Mortality associated with scavenging on road-kill carcasses has also been documented throughout the species' geographic range, and can be a substantial source of anthropogenic mortality (Hunt 2002, Hunt et al. 2017). Compensation for the loss of breeding areas and individuals must be sufficient to offset all of these impacts to ensure a stable or increasing population, yet little is known about the effectiveness of proposed compensation measures.

### 3.4.2 Model Uncertainties and Refinement

As is common for many wide-ranging, long-lived raptor species, empirical data on stage-specific vital rates and movement were lacking for golden eagles in the DRECP study system. Sparse field data can impart bias and imprecision to estimates of population size derived from mechanistic demographic models. However, for wide-ranging, difficult to study species, a precise estimate of the rate of population decline is of less use than a reliable assessment of the relative efficacy of two or more management strategies for slowing or reversing that decline (Schumaker et al. 2014). The team further emphasizes that the modeling framework presented here is extendable, not only in space, but also in terms of adding more biological detail from field studies. Sources of parameter uncertainty in the model stemmed from implicit assumptions made during development, which facilitates tractability and future assessment of these uncertainties within an analytical context. For example, a female-only model was used, which does not account for pair interactions and behavioral (e.g. Allee) effects on population vital rates – effects that are often associated with small population size and low density (Keitt et al. 2001). Sensitivity of the model to these and other assumptions could be explored by developing alternative and more complex model structures. Nonetheless, increasing realism also entails greater model complexity, and too many input parameters and submodels can confound interpretation and communication of results.

Uncertainty regarding model structure and vital rates for this study system is likely to persist, especially because many demographic traits of golden eagles are difficult and expensive to directly measure in field studies. This sensitivity analysis helped to address uncertainties about which demographic parameters had the strongest influence on population trajectories. Relatively small changes to some parameters (e.g., survival, fecundity, immigration, resource acquisition) resulted in disproportionately large effects on population size, indicating areas of focus for future monitoring, research, and management. For example, genetic analyses (Rudnick et al. 2005, Doyle et al. 2014) and use of camera-traps for individual mark-recapture studies are promising methods that could be used to improved estimates of stage-specific movement patterns and adult and pre-adult survival in the study area. The model also identified ecological relationships of disproportionate influence that could be prioritized within a monitoring framework, particularly with respect to habitat quality as affecting survival and successful reproduction, and nesting habitat and prey availability as affecting breeding and foraging success. Better empirical estimates of these relationships could improve the realism and predictive capabilities of the model. In addition, the sensitivity of the model to changes in immigration and emigration rates suggested that larger simulations conducted at broader

spatial scales are necessary to capture the importance wide-ranging movements of pre-adult eagles (Murphy et al. 2017) in maintaining demographic stability among localized populations.

### **3.5 Applications for Monitoring and Conservation**

This study demonstrates the novel use of a visual and quantitative tool to map, conceptualize, and forecast potential population responses of golden eagles to disturbances caused by renewable energy development or other anthropogenic stressors. The management-relevance of the model stems from its use of dynamic resource and disturbance maps of actual landscapes as principal drivers influencing simulated biological, ecological, and behavioral mechanisms that determine long-term population dynamics. This capability was demonstrated by evaluating whether the established conservation goals of the DRECP are likely to be met under a range of different risk scenarios. Variability in model output showed that the spatial distribution of breeding territories relative to future, site-specific threats strongly influenced mortality processes, and consequentially, total population size. This result highlights the value of using flexible tools for risk-assessment that incorporate spatially dependent processes when determining potential consequences of management activities to golden eagles.

In territorial species, individuals occupying different habitats may experience different probabilities of survival or reproduction depending on the amount and availability of resources within the area they occupy (Ferrer and Donazar 1996, Balbontin et al. 2003). As a consequence, individuals occupying the most productive sites (i.e., those with greater availability of resources with minimal disturbance), should show less variability in reproduction and be less affected by fluctuating environmental conditions. Spatial patterns of site quality emerged in the model from dynamic linkages between survival, reproduction, and the distribution of threats and resources in each simulated eagle's home range. Mapped output from the model illustrated how some breeding territories contributed more to maintaining long-term stability in population size than others—territories in the eastern portion of the DRECP essentially acted as sources (births outnumbered deaths), whereas breeding territories in the north and southwest acted as sinks (deaths outnumbered births). Differences among breeding sites in productivity has been documented in empirical studies of golden eagles (e.g., Hipkiss et al. 2014), and was an emergent property of the model resulting from spatial variability in food supply, disturbances, and competition with other simulated eagles. In this respect, the model predicted specific areas that may contribute most to long-term productivity of the local eagle population.

Golden eagles are long-lived, wide ranging apex predators that are logistically challenging and expensive to study, especially at broad spatial scales. This work represents an important next step in the longer term goal of developing modern, defensible forecasting models in general, and for demographic modeling of golden eagles in particular. Spatially explicit, individual-based models provide a framework to better understand the population dynamics that emerge from decisions that individuals make as they interact with complex and variable landscapes. The modeling framework presented here allows researchers and decision makers to: (1) make better informed choices about what specific areas should be prioritized for conservation, (2) synthesize biological data to evaluate potential responses to management actions, (2) determine the likelihood that implementation of a particular management strategy will meet established



conservation goals, and (3) investigate the importance of broad-scale population processes, such as metapopulation dynamics, that are difficult and costly to study in golden eagles.

## **CHAPTER 4:**

### **Overview of Monitoring Options**

Survey and monitoring options to estimate population size and trend in the plan area were discussed by experts at the DRECP Golden eagle Monitoring Plan Meeting, but none of the methods discussed were thoroughly reviewed or selected for implementation. As a consequence, the following section provides relevant background and a brief review of approaches that could be used for monitoring relative to goals and objectives outlined in Chapter 1.

#### **4.1 Population and Habitat-based Monitoring Strategies**

The conceptual model for golden eagles highlighted several sets of indicators that could be used to guide development of monitoring options. Indicators of population status included territory occupancy and turnover rates, reproduction, survival, and, ultimately, total population size and rate of population change ( $\lambda$ ). In Chapter 3, output from the demographic simulation analyses suggested that the most informative parameters for monitoring system state were adult survival, pre-adult survival, territory occupancy, reproduction, and immigration and emigration movements.

In this section, several alternative options are evaluated for determining status and tracking trends over time in these indicators, as well as their potential response to management actions. This evaluation focused on capabilities of several approaches used to survey and monitor golden eagles or other wide-ranging avian species, including: 1) individual mark-recapture studies of survival, 2) systematic surveys of nests, territory occupancy, reproduction, and abundance, and 4) line-transect density surveys (i.e., distance sampling). The team also evaluated several other potentially useful methods to monitor population indicators of golden eagles, such as stable isotope analysis to monitor immigration into the DRECP from elsewhere (Katzner et al. 2016), and non-invasive (genetic) mark-recapture techniques to monitor survival. Based on recommendations received from scientists and regulatory officials (Appendix A), the team also considered the assessment capability of monitoring options relative to the goal of building a predictive population model that could be used to inform long-term monitoring and determine effectiveness of proposed management actions in maintaining the local breeding population.

##### **4.1.1 Options for Population Monitoring**

###### **4.1.1.1 Individual Mark-Recapture Studies**

Individual-mark recapture studies have been used with effectiveness to understand potential responses of golden eagles to wind energy development (e.g., Hunt et al. 2017). The general approach of this option would be to assess space-use and demographic rates of golden eagles directly during pre- and post-construction phases using a before-after-control-impact (BACI) framework. For example, territorial individuals could be captured at breeding territories and marked with unique leg bands that could allow the bird to be identified in subsequent years without recapture. A clear advantage of individual mark-recapture studies is that resulting

data should permit estimation of annual apparent survival probability of breeders, territory turnover rates, and other measures of individual fitness (e.g., fecundity) if sufficient samples of eagles are individually marked. Capture-mark-recapture methods used to estimate demographic rates are extremely sensitive to sample size (number of individuals marked), which may limit the usefulness of these approaches to the sparse population of eagles in the DRECP. In addition, the USFWS specifically discourages capture and telemetry of golden eagles for impact assessments because of the unknown effects of capture and auxiliary marking to individuals and small populations (USFWS 2013).

Non-invasive mark-recapture methods, such as collection of feathers for genetic analysis, can also be used to estimate and monitor population size of wide-ranging raptors (Rudnick et al. 2005, 2008). Unique genetic markers are used to identify individual birds and identify the genetic structure of the resident population of eagles. In addition to identifying individuals, this information could also be used to track the components of the population such as floaters, juveniles, and sub-adults that are difficult to track with other monitoring methods (Katzner et al. 2011). Genetic approaches have been effective at monitoring turnover of adult eagles at territories (also an indicator of adult survivorship), mating systems, genetic relatedness and population structure, and numbers of non-breeders within a population (Rudnick et al. 2005, 2008). More recently, a single nucleotide polymorphism assay has been developed that may provide a cost-effective tool to determine these population attributes (Doyle et al. 2014).

There are advantages and limitations of non-invasive mark-recapture approaches when applied to golden eagles. For example, whereas traditional mark recapture studies involve time-, labor- and cost-intensive trapping of individuals, the field work for genetic studies is radically simpler, often involving simply picking up feathers at nest or roost sites or rappelling into a nest to collect a single feather from a growing nestling. As a consequence of this simplicity, sample sizes associated with genetic monitoring are often dramatically larger than is possible using traditional mark-recapture studies. For example, at eagle nests in Kazakhstan, with only about 10 days of field work, a team of two biologists was able to collect samples from 20-35 nest sites per year over a 3-year period. The limitations to genetic monitoring described here are mostly associated with project management; in particular: (1) research teams must involve collaborations between skilled field biologists and skilled laboratory biologists; (2) for historical reasons, conservation agencies often prefer to fund field, not laboratory, studies, and genetic work is sometimes not seen as directly relevant to field conservation priorities; and (3) permitting for collection, transport, and possession of eagle feathers is cumbersome and can impede research.

#### 4.4.1.2 Surveys of Site Occupancy, Reproduction, and Abundance

Non-invasive, population-level surveys of occupancy, reproduction, and abundance can be a cost-effective approach to document changes in the status of species over broad spatial scales. In particular, monitoring of occupancy (i.e., detection/non-detection surveys of a species at a set of predefined areas) has seen increased use as shrinking budgets have motivated using less expensive alternatives to intensive individual mark-recapture approaches to monitoring a

population's status (Bailey et al. 2014, Conner et al. 2016). Analyses of site-occupancy have been widely adopted in wildlife studies and applied to a diverse set of objectives, including habitat modeling (e.g., Ball et al. 2005), metapopulation studies, and large-scale monitoring efforts (e.g., Pellet and Schmidt 2005). Occupancy modeling also permits researchers to explicitly model colonization and extinction processes that can change the status of sites (occupied or vacant) over time using multi-season, dynamic modeling (MacKenzie et al. 2006).

Golden eagles may be difficult to detect during surveys, depending on physiographic conditions or period of the breeding cycle, so strong inference for occupancy studies requires accounting for imperfect detection (i.e. the inability of researchers to detect a species at a sample site with 100 percent certainty). Failing to account for imperfect detection can lead to inaccurate estimates of population parameters, such as the proportion of sites that are occupied, the proportion of sites with successful reproduction, or abundance (MacKenzie et al. 2006, 2009, Nichols et al. 2007). Probabilistic sampling designs based on site occupancy models have been shown to be particularly useful for investigating the dynamics of occurrence and distribution of sensitive bird species relative to landscape features or human land-use activities (e.g., Hagen et al. 2016, Lee and Bond 2016), including golden eagles (Booms et al. 2010, Wiens et al. 2015, Olson et al. 2015, Martin et al. 2009). Methods are now well developed for using detection/non-detection survey data to estimate dynamics in site occupancy and reproduction, while accounting for imperfect detection (Nichols et al. 2007, MacKenzie et al. 2009, 2010, Lee and Bond 2016). A multistate occupancy study design considers multiple biologically relevant states, such as breeding or nonbreeding, which provides an especially useful framework for investigating reproduction by accounting for the potential effects of the previous year's occupancy state (i.e., vacant, occupied with no young, or occupied with young). In the case of golden eagles in the plan area, this framework can be used to estimate, analyze, and map spatial patterns of occupancy and reproduction. Such information is a key requirement for conservation policy that aims to maximize breeding success and maintain stable breeding populations (USFWS 2013, CEC 2011, 2014).

The team considered surveys of occupancy, reproduction, and abundance to fall under a general classification of dynamic site-occupancy studies (MacKenzie et al. 2006). For golden eagles, these surveys have included: 1) searches of a set of historical nesting territories (Steenhof and Newton 2007, Steenhof et al. 2014, Martin et al. 2009), 2) use of point-counts to estimate use at a set of randomly placed sample locations (USFWS 2013), or 3) area-based searches of randomly placed sample plots (Wiens et al. 2015). Below each approach estimates site occupancy for golden eagles.

#### *Nest Surveys*

Surveys of raptor nests are typically used to assess occupancy, or use, of known nest locations, find new nests, and to document reproduction (i.e., number of young fledged). Surveys of golden eagle nests are typically conducted either from the ground or via helicopter, where areas containing known and potential nesting areas of golden eagles are searched to determine occupancy status of known nests and to identify new nesting locations (e.g., Martin et al. 2009). Data obtained from nest surveys include: (1) the detection/non-detection of territorial golden

eagles at nests, (2) the location and condition of known and newly discovered nests, and (3) the breeding status and reproductive output of territorial pairs.

Aerial surveys of known or potential nests would be conducted according to guidelines provided in the (draft) Interim Golden eagle Inventory and Monitoring Protocols and Other Recommendations (Pagel et al. 2010).

At least two checks via aircraft or two ground-based observations are recommended by USFWS (2013) to designate a nest or territory as unoccupied, given that all potential nest sites and alternate nests are visible and monitored (i.e., alternate nests may be widely separated such that a ground-based survey should be devoted to each). Surveys of nests tend to be spatially constrained, however, and may not provide accurate estimates of territory occupancy for birds that are not nesting (Millsap et al. 2015). For this reason, it is useful to couple more extensive ground surveys with aerial surveys of known nests, which can further supplement information on new nests and better document activity centers of territorial pairs of golden eagles observed during surveys (McIntyre and Schmidt 2012, Wiens et al. 2015). Ground-based observations are recommended to be conducted for at least 4 hours per visit (nesting status may be verified in less time), aided by spotting scopes, from at least 0.8 km from the nest(s), during weather conducive to eagle activity and good visibility (USFWS 2013). Nest surveys should include a representative sample of potential nesting resources used by golden eagles in the plan area. By mapping specific landscape features (e.g., cliffs) and vegetation cover-types (e.g., grassland or shrub-steppe) that are potentially suitable for nesting or foraging by golden eagles, it is possible to make basic assessments about whether a particular site has ecological value to the species.

*Point-counts (USFWS approach).* For wind energy projects the USFWS provides recommendations specific to preconstruction surveys for eagles via the Eagle Conservation Plan Guidance (USFWS 2013). Specifically, USFWS (2013) recommended use of 800-m (~200 ha), fixed-radius point counts, conducted over a period of at least one hour to record the presence and behavior of golden eagles and other large birds. The protocol suggests a stratified, random, spatial distribution of sampling points to cover 30% of the area within 1 km of proposed and alternative wind-turbine locations. Estimates of use for the 800 m fixed-radius points are then used within a Bayesian modeling framework to identify risk to eagles from the proposed project (USFWS 2012). Projects that have used the USFWS (2013) point-count approach to address potential risk and disturbance have typically reported observation rates of golden eagles (e.g., number of minutes eagles were observed per hour of observation) and a map of locations where eagles were seen.

A potential weakness of the USFWS (2013) point-count approach is that it fails to account for imperfect detection of eagles during surveys, which can result in underestimating the use of a particular site by eagles. Recent attempts to overcome this issue used occupancy modeling with point-count data on golden eagles to account for imperfect detection, but results were strongly dependent upon the radius in which point counts were determined (Skipper et al. 2017). Moreover, a mismatch between the scale of observation (an 800-m radius around a randomly located sample point; USFWS 2013) and the scale at which wide-ranging eagles operate creates ambiguities in how parameter estimates are interpreted.

### *Occupancy Surveys at a Set of Historically Used Breeding Territories*

Monitoring occupancy at a sample of territories historically occupied by golden eagles (for example territory-based surveys) is a common approach used successfully to track the breeding segment of golden eagle populations elsewhere (such as Martin et al. 2009). A common approach to monitoring the breeding component of a population of golden eagles is to identify a sufficient sample of breeding areas occupied by territorial pairs of eagles, and then monitor for changes in use and reproduction at these sites over time. This approach has also been used widely in monitoring programs for other sensitive avian species (such as Lint et al. 1999).

Under a territory-based survey design, care must be taken to ensure the sample of territories is representative of the population of interest, and not just those that are convenient to monitor or consistently used by eagles. Moreover, because only historical areas used by golden eagles are sampled under this approach, inferences are unequivocally limited to occupancy or use of historical territories (i.e. sites used at some point by eagles). This highlights an important inferential shortcoming of territory-based surveys, in that they may not provide unbiased inference on the demography and habitat associations of golden eagles across an entire landscape.

### *Monitoring Site Occupancy, Reproduction, and Intensity of Use With Random Plots*

Wiens et al. (2015) used a multistate occupancy sampling design to estimate site-occupancy, breeding success, and abundance of territorial pairs of golden eagles in the Diablo Range of west-central California. Their method uses the spatial pattern of detections and non-detections over repeated visits to randomly place survey sites to estimate probabilities of occupancy and successful reproduction, while accounting for imperfect detection of golden eagles and their young during surveys. Results emphasized the importance of accounting for imperfect detection and spatial heterogeneity in landscape conditions in assessments of occupancy and reproduction of golden eagles. The method also provided useful information for conservation prioritization for golden eagles by helping to identify important linkages between landscape composition and population vital rates. The multistate occupancy study design offers a potentially promising technique for monitoring the spatial distribution of occupancy and reproduction of golden eagles in the DRECP area if alternative, more intensive mark-recapture methods are determined to be overly limited by logistics, accessibility, or budget constraints. Importantly, surveys conducted under a randomized plot design are linked to a probabilistic sampling design such that inferences and conservation efforts are not vulnerable to potential biases associated with only sampling areas that were known to be historically used by eagles.

Studies of dynamics in territory occupancy in raptors frequently ignore variation in abundance of occupied sites, even though site abundances affect many of the occupancy parameters of interest (e.g., extinction, colonization, detection probability). Recently, Rossman et al. (2016) developed “dynamic N-occupancy models”, capable of providing accurate estimates of local abundance, population gains (reproduction, immigration), and apparent survival probabilities while accounting for imperfect detection using only data from repeated surveys to a set of sample sites. The dynamic N-occupancy model is the first to allow estimation of individual demographic rates from broad-scale detection/non-detection data, one of the most widely collected data types (MacKenzie 2005), allowing for comprehensive inference at broad spatial

extents. For monitoring golden eagles, this method could allow researchers and managers in the DRECP area to produce unbiased and precise estimates of demographic rates across space and time using only data collected from site-occupancy surveys of golden eagles.

A major benefit of a site-occupancy approach to monitoring golden eagles is that it circumvents the logistical difficulties and expense of a large-scale mark-recapture study. In addition, recent methods (Rossman et al. 2016) permit extensions of basic site-occupancy models that could provide information on important indicators of population status (i.e. reproduction, immigration, adult and pre-adult survival). As a consequence, the team suggests that a site-occupancy approach to monitoring could provide a cost-effective and powerful means to track population trends of golden eagles in the DRECP area. A potential weakness of site-occupancy studies is that resulting inferences are based on sites, not individuals, so they do not provide demographic information at the individual level required to separate site-quality from quality of individual birds.

#### 4.4.1.3 Line Transect Surveys (Distance Sampling)

##### *Aerial Line-transect Surveys*

In 2003, the USFWS contracted with Western EcoSystems Technology, Inc. (WEST) to design and conduct an aerial line-transect survey for golden eagles across the western U.S. The goal of the 2003 survey was to develop and test methods for estimating abundance and monitoring trends across much of the western U.S. (excluding the majority of California). The surveys involve flying broad swaths of the landscape at low altitude and relatively low speeds from a fixed wing aircraft. During the flight, nests and golden eagles are counted. Like other transect-based survey techniques, the results are considered a representative sample and are extrapolated across a broader area to estimate population size of golden eagles.

George et al. (2014) examined the feasibility of estimating density and abundance of golden eagles in the DRECP area using broad-scale aerial surveys. The researchers flew aerial surveys between July 31-August 6 (post-fledging surveys) and December 9-15, 2013 (winter surveys). During the post-fledging surveys, two golden eagle groups were observed. Three golden eagle groups were observed during the winter surveys. Because of the low sample sizes, the researchers combined observations in the DRECP survey with observations from the Western-wide Golden Eagle Survey (Millsap et al. 2013) to estimate probabilities of detection for golden eagles in the DRECP area. Based on the proportion of the area surveyed and estimates of the probability of detecting golden eagles in the sample areas, the researchers estimated there were 80 (90 percent confidence interval 31 to 191) and 135 (90 percent confidence interval 41 to 340) golden eagles during the post-fledging and winter surveys, respectively.

It was determined that additional effort or a different survey design is needed to obtain a level of precision allowing detection of moderate changes in the eagle population over time. Changes to the survey design would require either conducting more than one pass over the area, increasing the density of transects or using information on golden eagle habitat associations to inform the placement of transect lines across the study area (George et al. 2014). A limitation of

this approach is that resulting estimates of abundance generally have poor precision, especially at localized scales (Millsap et al. 2013, George et al. 2014).

#### *Road Surveys*

Duerr et al. (2015) used road transects to survey raptors within the DRECP. The study design involved random placement of 24 transects along 25.6-km (16 miles) of paved and dirt roads in the DRECP area. All raptors, including golden eagles, were counted. Number of golden eagles counted (nine) were nearly twice that observed in aerial line-transect surveys conducted by WEST in 2003. As in George et al. (2014), the low number of observations of golden eagles in the Duerr et al. (2015) study was also insufficient for useful population estimation, so they used detection rates based on those estimated for similar species (turkey vultures and red-tailed hawks) for density estimation for golden eagles. Advantages of road surveys to estimate density and population size of golden eagles in the DREC include: (1) there is relatively good coverage of the DRECP area with roads, (2) they are comparatively less difficult and costly to implement as compared to aerial surveys, and (2) they may result in estimates that independently provide greater precision. A limitation of road surveys is that resulting inferences on eagle densities may be heavily restricted to habitats near roads, which may not be representative of areas without roads (e.g., areas with rugged terrain or cliffs).

#### 4.4.1.4 Stable Isotope Analysis

Stable isotope analysis has recently been used to understand large-scale movements of golden eagles (Nelson et al. 2015, Katzner et al. 2016). In brief, ratios among different isotopes of elements vary naturally in the environment. For example, hydrogen isotope ratios vary in response to isotope ratios in precipitation, and thus with latitude and elevation. Hydrogen isotope ratios in eagle feathers reflect hydrogen isotope ratios in the water that eagles or their prey ingest, so these ratios can be useful in geolocation. Nelson et al (2015) used hydrogen isotope ratios of telemetered migratory golden eagles to infer summer origins of migratory eagles captured during winter in the Appalachians. Katzner et al. (2016) used hydrogen isotope ratios of eagles killed at Altamont Pass Wind Resource Area to infer immigration rates to the region, and thus the continental-scale demographic consequences of local-scale wind energy development on eagles. Stable isotope analysis is a powerful and relatively inexpensive tool for geolocation. Because it relies on feathers, it can be done non-invasively without capture and may be referenced against captured and telemetered individuals. Stable isotope analysis can be used to detect movements across broad spatial scales, but is greatly limited in that geolocation is low-precision, providing inferences at the scale of hundreds or even thousands of kilometers. For example, this method could be applied to determine the frequency of long-distance immigration events by eagles from other, perhaps distant locations into the DRECP area.

#### 4.4.1.5 Combining Methods to Maximize Effectiveness

Methods for determining status and tracking trends in eagle populations were considered relative to the set of population indicators specified by the conceptual model; a summary is displayed in Table 4. The team also considered whether these methods provided data to inform



the demographic model that could be used to focus long-term monitoring and predict how proposed renewable energy projects may affect the local population of eagles.

Elsewhere, Katzner et al. (2006) used population simulation modeling to assess a monitoring program for Eastern Imperial Eagles (*Aquila heliaca*) in Kazakhstan. Their analysis showed that the parameters that were most informative about system state and sudden changes to system state may be different from those best suited to indicate long-term trends in the population. Their study suggested that threats that have immediate impacts (e.g., rapid increase in mortality of pre-adults) may not be adequately captured by monitoring occupancy of historically used territories. Alternatively, threats that are long-term (e.g., habitat degradation) were unlikely to be captured by changes in continuous parameters such as adult survival (Katzner et al. 2006). These authors suggested that a prudently designed monitoring program will detect the effects of both types of threats, and this requires monitoring combinations of population parameters.

Similar to the results of Katzner et al. (2006), the demographic model developed for golden eagles in Chapter 3 suggested that an ideal monitoring program will be capable of detecting changes in both long-term population trends and sudden demographic shifts, which will likely require a combination of sampling methods. For example, population size, productivity, and survival of golden eagles will be difficult to measure accurately and precisely in the early years of a monitoring program based on monitoring data alone. This is because a minimum of five years of survey data are required to estimate these parameters (such as Rossman et al. 2016), but also because the population varies naturally with environmental fluctuations, and threats to eagle populations are not homogenous and occur at widely varying temporal scales. Combining population surveys with more detailed studies of individual survival and movements (e.g., genetic mark-recapture, stable isotope analyses) would provide a more complete picture of current status of important population parameters.

**Table 4: Assessment Capabilities of Alternative Sampling Approaches Considered for Monitoring Population Trend of Golden Eagles in the DRECP Area, California.**

Monitoring Method	Estimation of Population Size?	Population-level Inference?	Population Vital Rates (Indicators)				Supports Predictive Demographic Model?
			Occupancy	Reproduction	Survival	Territory Turnover	
Individual mark-recapture	Yes	Limited to area sampled	Yes	Yes	Yes	Yes	Yes
Genetic mark-recapture	Yes	Limited to area sampled	Yes	No	Yes	Yes	Yes
Site-occupancy and reproduction (including N-occupancy)	Yes	Yes	Yes	Yes	Yes	No	Yes
Nest surveys (ground and aerial)	No	Breeding segment only	Yes	Yes	No	No	Yes
Distance-sampling (ground and aerial)	Yes	Yes	Yes	No	No	No	Yes
Stable isotope analysis of long-distance movement	Yes	Yes	No	No	No	No	Yes

#### 4.1.2 Habitat-Based Monitoring

The dynamic changes in primary productivity and availability of prey populations in the plan area reflect the underlying biotic and physical driving forces, including climate and human-caused disturbance. Monitoring these factors will be essential to determine the response of golden eagles, but there are many limitations to a strictly habitat-based approach to monitoring that must be carefully considered in the design of a long-term monitoring program. Such limitations include:

- Underlying uncertainties about habitat associations, prey resources, and population demography of golden eagles in the plan area limits the usefulness of this approach in early stages of monitoring. Some of this information is has been acquired for the Plan area (e.g., Longshore et al. 2017), but a concentrated research effort is required to establish linkages between golden eagles, their resources, and human disturbance.
- Establishing linkages between habitat conditions and population demography typically requires long-term data, and even then can be complicated by the emergence of new or unexpected threats. For example, the original monitoring plan for northern spotted owls called for the eventual shift from demographic to habitat-based monitoring strategies (Lint et al. 1999), but identifying linkages between owl demographics and habitat conditions have proven far more difficult to determine than originally planned.
- It is unknown how site-specific changes in habitat amount and distribution contribute to variation in population dynamics of golden eagles at different spatial scales. For example, changes in population size in the plan area could be caused by environmental changes elsewhere in the species' range that affects dispersal to the region.
- Changes in physiographic conditions of the environment do not necessarily predict response of golden eagle populations to ubiquitous stressors such as toxins (e.g., lead or rodenticide exposure) or competitive interactions.

Instead, a habitat-based monitoring approach is most effective when coupled with studies of population demography, and offers several advantages, including:

- Monitoring can build upon existing landscape inventory analyses to focus efforts on landscape conditions that promote resource availability for golden eagles;
- Estimating trends in disturbance of nesting and foraging conditions relative to population status of golden eagles represents a prospective approach to monitoring that, when coupled with predictive demographic models, can help anticipate effects of planned changes in land-use activities on golden eagles; and
- Golden eagles are apex predators with key biodiversity functions, so monitoring for concurrent changes in population status and foraging habitats of golden eagles can provide important indicators of the status of other associated wildlife.



## CHAPTER 5:

### Proposed Monitoring Approach

Selecting a monitoring approach and associated sampling options for golden eagles requires careful consideration of the trade-offs between cost, the spatial scale of inferential interest, and accuracy in measuring population change. The team's review suggested that the financial savings and increased scope of inference by monitoring site-occupancy and use of landscapes by breeding and non-breeding golden eagles may be worth the loss of more detailed demographic information obtained from individual mark-recapture studies (Chapter 4). Nonetheless, if land managers are mainly concerned with detecting declines of golden eagles within the DRECP, then trends in total size of the localized population could be missed or underestimated by strictly monitoring occupancy and reproduction at known historical territories used by breeding eagles. In addition, the simulation study of golden eagles (Chapter 3) indicated that an optimal monitoring approach would be capable of detecting short-and long-term changes in both the breeding and non-breeding segments of the local population.

Based on assessments completed in Chapters 2–4, the team proposes that monitoring in the plan area focus on precise and accurate estimates of site occupancy, reproduction, adult and pre-adult survival, and intensity of use of landscapes by breeding and non-breeding golden eagles. Such estimates can be obtained by combining broad-scale population surveys with more detailed studies of individual survival and movements.

As recognized by biologists and regulatory officials during the initial planning stages of the monitoring plan (Appendix A), an important aspect of the monitoring approach is to maintain a standardized, rigorous framework for collecting long-term data on golden eagles. As a consequence, the team suggests that a research team be developed early in the monitoring process that is maintained over the long term (as opposed to hiring a new research team each year).

The proposed monitoring approach includes four primary components:

- a. **Annual assessments of site-occupancy and reproduction by territorial pairs of golden eagles (including rates at which sites become colonized or vacated over time).**  
Monitoring occupancy/use and reproduction by territorial pairs of eagles at a sufficient number of sites (i.e. historical breeding territories or sample plots) can be used to detect long-term change in spatial distribution of eagle pairs and successful breeding. Nesting status and number of young produced per year by territorial pairs of eagles detected can be used to track spatial and temporal trends in reproduction. This information is useful for identifying areas of high productivity for conservation prioritization, in addition to areas of low productivity that provide important indicators of population status. In theory this information can also detect site-specific stressors (e.g., contaminants or disturbances) that reduce reproduction, but are unlikely to be reflected in estimates of occupancy or survival.

Information collected during site-occupancy monitoring activities may also include the proportion of breeding individuals with subadult plumage characteristics. This is relevant information because an increasing proportion of territorial pairs with subadult members can be an early warning of declines in the overall population (i.e. as fewer individuals are available to replace adult mortality at a limited number of breeding sites).

- b. **Estimates of survival, movements, and intensity of use of landscapes by breeding and non-breeding golden eagles.** Evidence indicates that the population rate of change in golden eagles in the DRECP area (and elsewhere) is strongly influenced by relatively small changes in adult survival (see reviews in Chapters 3, 4). The team's assessment also indicated that survival and movements of pre-adult eagles is relevant to maintaining breeding populations in the region. Monitoring changes in survival, and the factors affecting survival, can be used to detect short-term changes in mortality risk that may not be detectable from strictly monitoring site-occupancy. Local estimates of adult survival, with corresponding measures of uncertainty, are also necessary to refine the predictive capabilities of the demographic model (Chapter 3). Annual and seasonal movement patterns of breeding and non-breeding golden eagles, including patterns of space-use, seasonal migration, and immigration and emigration to and from the plan area (especially breeding birds) is also required to more fully understand how the local population of eagle is regulated (i.e. external vs. internal recruitment).
- c. **Periodic (conducted every 2–4 years) assessment of primary prey populations and foraging habitats.** Information on prey populations and foraging habitats of golden eagles is necessary to track shifts in resource availability for eagles in the plan area. It is proposed that the monitoring plan include periodic assessments of associations between occurrence and reproduction of golden eagles and vegetation, prey resources, climate, and landscape disturbance. Golden eagles are closely linked to the distribution of their food resources, so information on eagle diets and prey populations permits land managers to identify how the eagle population responds to changes caused by resource availability relative to other stressors or disturbances. Relevant data include dietary composition of breeding pairs, and the spatial distribution and availability of primary prey (e.g., lagomorphs and ground squirrels; Longshore et al. 2017). This information also permits researchers and managers to identify the distribution of habitats and prey resources associated with high-quality nesting and foraging areas (also see Chapter 3). This is relevant because the proposed monitoring approach emphasizes the importance of monitoring poor quality territories (i.e., low productivity) as early indicators of a population decline, as these sites are predicted to have a greater probability of being vacated by eagles under a scenario of a decreasing floater pool.

Data on prey availability and foraging habitats can be collected in a way that allows for detection of long-term changes in these limiting factors (Chapter 2). This includes measurements of the spatial distribution of available nesting and foraging habitats, in addition to associations with primary productivity, climate, and human land-use (such

as Figure 4). Accurate and regularly updated spatial information is required to inform landscape productivity and disturbance within the spatial demographic model, especially at planned Development Focal Areas (CEC 2014; Chapter 3).

- d. **Updating the baseline predictive demographic model with new information obtained on eagles and population stressors.** Information gained on the occurrence, distribution, reproduction, survival, and movements of eagles outlined in components 1–3 above can be combined with information collected on the spatial distribution of high-quality nesting and foraging areas. The combined data sets can then be synthesized to inform and refine the predictive model of eagle distribution and population dynamics developed in Chapter 3. This modeling approach provides a valuable decision-support tool for forecasting the potential consequences of proposed development, permitting, and conservation scenarios to golden eagles in the DRECP area.

## 5.1 Population and Habitat Monitoring, Phases I and II

It is generally recognized by biologists and regulatory officials that additional research is needed to identify effective measures to offset impacts of development to golden eagles at the population level, and to determine how the DRECP might afford additional permitting flexibility in this respect (CEC 2014; also see Appendix A). As a consequence, data collection under the proposed golden eagle monitoring plan is applied in two phases. Phase I focuses on a set of detailed studies designed to quickly gain information on key demographic parameters of golden eagles (survival, reproduction, movements), current status of the local population (for example stable, increasing, or decreasing), and the spatial distribution of known and possible threats and resources. Population surveys of breeding and non-breeding golden eagles (site-occupancy studies) are a key component of data collection, analysis, and reporting in Phase I. Studies of prey and foraging habitats of eagles relative to planned development activities are also implemented in Phase I, and some of this work has already been initiated (such as Longshore et al. 2017). As shown in Chapter 3, information on prey availability in combination with data on site occupancy and reproduction provide a means for tracking changes in the spatial distribution of specific areas that promote high productivity by golden eagles. Estimates will require the compilation of landscape features and vegetation conditions in the plan area with population surveys of golden eagles and their prey so that maps of resource availability can be updated. In the later part of Phase I, information gained on the occurrence, distribution, and demographic rates of eagles is combined with concurrent information on the spatial distribution of high-quality nesting and foraging habitats. Those data sets are then synthesized as input to the predictive demographic model to assess population status, and to characterize potential outcomes of proposed site-specific permitting and management actions in the plan area.

Phase II of the monitoring plan de-emphasizes the more intensive studies of survival and movements implemented in Phase I, shifting to less-intensive population surveys and periodic assessments of prey populations and foraging habitats. Information gathered in Phase II is used to track long-term status of the population. It is emphasized that population surveys of

breeding and non-breeding golden eagles are a key component of data collection, analysis, and reporting during both phases of implementation.

The monitoring approach outlined here relies heavily upon an active research effort in the near term to update and refine predictive demographic models capable of relating population dynamics of eagles to environmental variation at multiple spatial scales. As a consequence, inferences about the baseline status of the local population of golden eagles in the near term can be centered primarily upon results from broad-scale population surveys (e.g., George et al. 2014, Wiens et al. 2015), in addition to more focused studies of survival and movements. As the predictive demographic model is refined with new baseline information on spatial and temporal variation in indicators of populations and habitats, they can also incorporate observed changes in environmental conditions associated with planned development activities.

## **5.2 Recommended Sampling Options**

### **5.2.1 Surveys of Site Occupancy, Reproduction, and Abundance**

Based on a review of sampling options relative to the specific goals of the monitoring plan, the team recommends that population surveys of golden eagles include a site-occupancy design capable of providing precise estimates of occupancy, reproduction, abundance, and rate of change in occupancy parameters. Studies of site-occupancy (i.e. those based on detection/non-detection data and counts of eagles obtained from repeated surveys at a sufficient number of pre-specified sites) could be designed so that newer analytical methods can be applied to estimate relevant demographic parameters (e.g., population gains and apparent survival) while accounting for imperfect detection during surveys (Dali and Madsen 2011, Rossman et al. 2016). Note that Rossman et al. (2016) recommended a minimum of five years of occupancy (count) survey data are needed to provide reliable and precise estimates of population gains and survival. This approach to monitoring golden eagles also focuses on identifying the distribution of physiographic conditions that are most strongly associated with 'high' and 'low' quality sites, based on observed spatial differences in use by eagles among sample sites, as well as differences among sites in occurrence and reproductive output of territorial pairs of eagles. This option accommodates the importance of monitoring poor quality sites (i.e. those with low productivity or intermittent occupancy by pairs of eagles) as early indicators of a population decline.

### **5.2.2 Non-invasive Mark-recapture Studies**

Survival of pre-adult and adult golden eagles are other especially relevant indicators of population status because: 1) population growth rate of golden eagles in the plan area appeared to be disproportionately sensitive to relatively small changes in adult survival rate (Chapter 3); and 2) survival may be sensitive to changes in human-land use and development associated with renewable energy projects (e.g., collisions with wind-turbines or vehicles). As reviewed in Chapter 4, non-invasive mark-recapture methods, such as collection of feathers for genetic analysis, could be used to estimate and monitor for changes in survival of eagles, or even population size (Rudnick et al. 2005, 2007). In addition to identifying individuals, this method could also be used to track relevant components of the local non-breeding population of eagles, such as floaters, juveniles, and sub-adults that are difficult to track with other monitoring methods (Katzner et al. 2011). As a consequence, the team suggests that broad-scale surveys of



site-occupancy, reproduction, and abundance be coupled with more focused studies of survival (e.g., Rudnick et al. 2005, 2007).

### 5.2.3 Long-Term Monitoring at Multiple Spatial Scales

A multi-scale approach to monitoring is necessary for regular assessments of the extent of project- vs. population-level effects of renewable energy development on golden eagles. A monitoring design that can be used in conjunction with ongoing USFWS monitoring of golden eagles at regional and national scales is also highly desirable (Appendix A). In addition, a multi-scale approach to monitoring is required to capture the wide range of environmental conditions and threats that likely influence population dynamics. As a consequence, the monitoring plan team proposes that broad-scale surveys of site-occupancy be coupled with regional surveys of total population size of golden eagles in the plan area. Studies of site-occupancy, which include estimates of use of landscapes by breeding and non-breeding golden eagles, provide information at the project- and population-level, while regional surveys of total population size provide broader information that can ultimately be coupled with national survey efforts for golden eagles. Further details on this multi-scale survey framework are provided in Chapter 6 (*see Survey Level Descriptions and Standardized Field Protocols*).



# CHAPTER 6:

## Implementation and Refinement

### 6.1 Proposed Survey Design and Field Protocols

#### 6.1.1 Survey Level Descriptions and Inferences

Regulatory officials and research biologists have suggested that a range of monitoring options for golden eagles in the DRECP is desirable, based on costs and inferential considerations (Appendix A). The team characterized three inter-related survey levels that range from least extensive in coverage and lowest expense (Level 1), to more complete coverage and potentially higher cost (Level 3). Note that survey levels 1 and 2 are conducted during both Phase 1 and Phase 2 of the monitoring plan to quickly gain detailed information on relevant indicators of population status (Chapter 2, 5). Level 3 population surveys provide broad-scale, regional estimates of overall abundance of golden eagles than may be linked with efforts to estimate population size of eagles at much broader scales (Millsap et al. 2013, George et al. 2014).

- Level 1 (project-level monitoring): assessment of proposed project site ‘use’ by golden eagles (e.g., USFWS 2013; Eagle Conservation Plan Guidance – Module 1).
- Level 2 (local DRECP population): survey level 2 monitoring includes the same areas monitored as in survey level 1, but also includes assessments of occupancy and reproductive output of territorial pairs proposed in Chapter 5 (such as random plot multistate occupancy surveys to track trend in occupancy and reproduction at broad spatial scales and identify “high” and “low” quality territories in landscape).
- Level 3 (DRECP-regional scale): line-transect surveys of density and total population size of golden eagles (for example aerial surveys [George et al. 2014]; road surveys [Duerr et al. 2015]). Surveys can be used in conjunction with regional/national monitoring efforts.

#### 6.1.2 Estimation of Occupancy, Reproduction, and Intensity of Use

The DRECP area includes a mixture of lands in public and private ownership (CEC 2014). Surveys of golden eagles in this area cannot necessarily be performed in all possible areas potentially used by eagles because of limited access to some areas, logistical challenges, and budget restrictions. As a consequence, it is proposed that population estimates be obtained using a statistically rigorous sampling design that permits inferences to the entire area of interest, rather than being restricted to a limited number of known breeding areas historically used by eagles.

A probabilistic sampling design capable of inferring estimates of site-occupancy, reproduction, and abundance (or use) across the entire DRECP area is desirable. As described in Chapter 4, a dynamic multistate approach to monitoring occupancy and reproduction has been used for a number of raptor species, including golden eagles (Martin et al. 2009, Wiens et al. 2011, 2015, Bruggeman et al. 2016).

Benefits of a similar design for golden eagles in the DRECP area include:

- The ability to estimate and accommodate imperfect detection of eagles and their nests during surveys, increasing the ability to detect trends in site-occupancy and reproductive success of territorial pairs of eagles over time.
- The ability to link estimates of site occupancy and reproduction to habitat, land-use patterns, and other variables of interest, thus separating changes in the factors of interest from other confounding sources of variation.
- The design and resulting survey data directly inform information needed to refine estimates from the predictive demographic model developed in Chapter 3. A survey design compatible with the demographic model can help better inform adaptive management, in accordance with the prioritized requirements for baseline monitoring objectives outlined for eagles in the DRECP.
- The design permits monitoring data to be analyzed jointly with other similar studies (e.g., Wiens et al. 2015), thereby providing a regional context for interpreting monitoring data collected on eagles in the DRECP region.
- The design permits relevant demographic rates (reproduction, apparent survival, and occupancy dynamics) to be estimated without marked individuals, thereby providing a non-invasive and more cost-effective approach to monitoring golden eagles at multiple spatial scales.

In the following sections an example of a multistate occupancy sampling design, and associated survey protocol, is provided that could be used to detect and estimate short- and long-term trends of golden eagles in the DRECP area. This study design was first established and implemented successfully for a local population of golden eagles exposed to mortality caused by wind-energy in west-central California (Wiens et al. 2015), and more recently in San Diego County of southern California (R. Fisher, USGS, personal communication).

A multistate occupancy sampling framework was considered where randomly placed survey sites are classified as unoccupied (state = 0), occupied by one or more territorial pairs of eagles with no young (state = 1), and occupied by one or more territorial pairs with successful reproduction (i.e.  $\geq 1$  young fledged; state = 2). Under this survey design, failure to detect young at a site does not necessarily indicate absence of successful reproduction, but instead admits the uncertainty associated with determinations of nesting status (Nichols et al. 2007, Wiens et al. 2015). Survey sites targeted for repeated surveys of golden eagles are selected randomly from a grid of equal sized hexagonal cells overlaid on the plan area (such as Figure 10). Random selection of sample plots for surveys permits inferences to be extended over the entire area samples (i.e. the DRECP area), and can be stratified by habitat suitability class if necessary. The size of each hexagon sample unit corresponded with the mean size of the breeding territory (i.e., area of concentrated use, or core-use area) for territorial golden eagles in the study area. The size of sample sites can be estimated from observed nearest neighbor distances or telemetry data on territorial adults. On each survey, observers establish 1–4 observation points on

selected ridges and hilltops to provide complete coverage of the focal sample site. Observers then search for evidence of occupancy and reproduction by territorial pairs of eagles for up to a four hour observation period. Observers also classify and count all eagles detected as juveniles, subadults, or breeding/non-breeding adults based on visible plumage characteristics and behavioral observations (Bloom and Clark 2001, Wiens et al. 2015). The design permits a combination of aerial and ground-based surveys to be used to conduct repeated surveys of golden eagles and search for evidence of nesting.

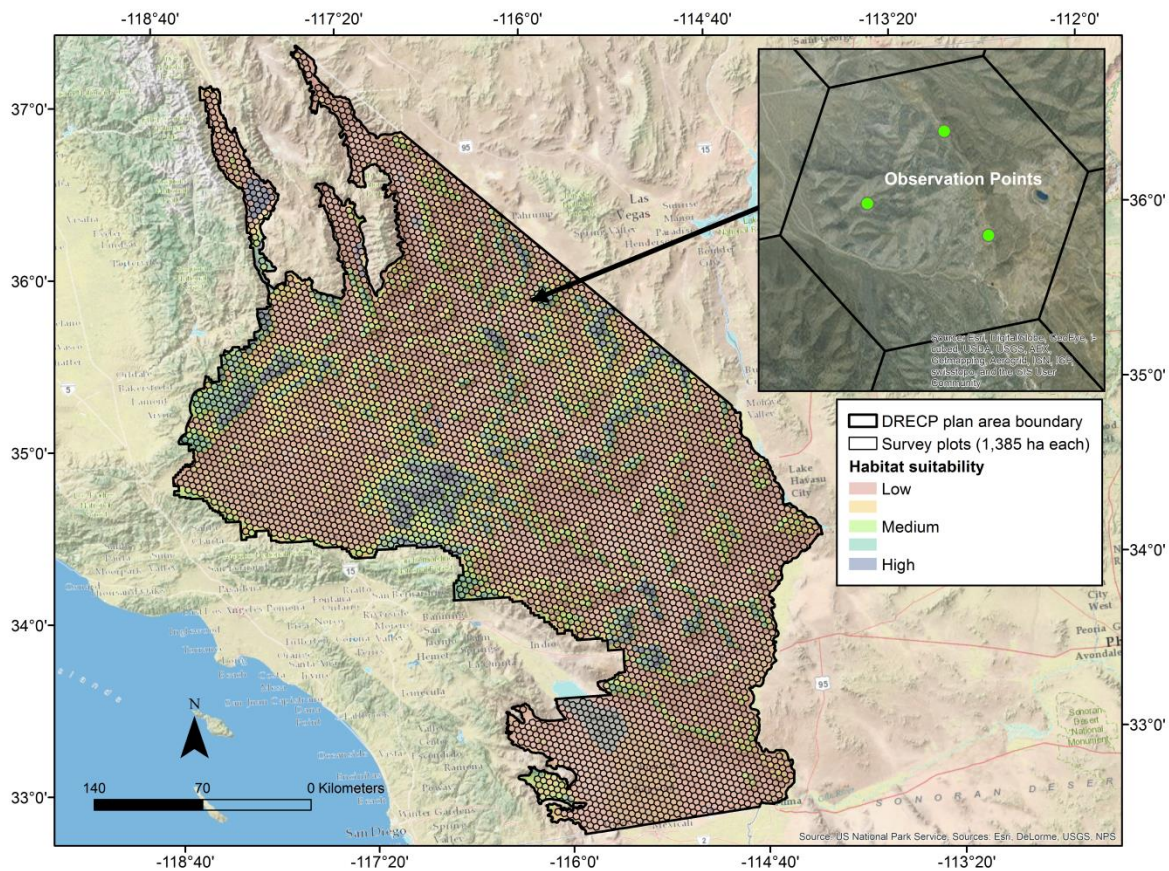
To optimize the proposed multistate occupancy survey design for eagle in the DRECP, a series of simulations were performed in Program GENPRES (Bailey et al. 2007) to determine how different allocations of survey effort (i.e. number of survey sites) affected precision in estimates of occupancy ( $\psi^1$ ) and successful reproduction ( $\psi^2$ ) under a range of possible detection probabilities. For estimates of precision in occupancy parameters, a desired coefficient of variation (CV) of  $\leq 0.20$  was targeted, where  $CV = [SE(\psi)/(\psi)]$  (MacKenzie et al. 2002). The team assumed probabilities of occupancy (0.10, 0.40, 0.60), success reproduction (0.10, 0.50, 0.65), and detection (0.30, 0.50, 0.70), and four visits per site in Program GENPRES to obtain estimates of the minimum number of survey sites required to achieve a desired CV of  $\leq 0.20$ . Four repeat surveys at each site were used because this is the minimum number of surveys recommended for determinations of site occupancy and reproductive status for golden eagles (Driscoll 2010, Wiens et al. 2015). In addition, the team also simulated sampling requirements under poor ( $\psi^2 = 0.10$ ) versus good nesting conditions ( $\psi^2 = 0.65$ ). Detection probabilities that varied over the course of a single survey season were used to reflect observed seasonal changes in detectability of territorial pairs of golden eagles (Driscoll et al. 2010, Wiens et al. 2015). Sigma ( $\delta$ ), the probability that evidence of successful reproduction is found, was held constant for all simulations using estimates of these parameters reported in Wiens et al. (2015).

**Table 5: Simulation Results for a Range of Potential Survey Designs Considered for Estimating Site Occupancy ( $\psi^1$ ), and Reproduction ( $\psi^2$ ) of Golden Eagles in the DRECP Area.**

True Parameter Values				Number of Sites	
$\psi_1$	$p_1$	$\psi_2$	$p_2$	$\hat{\psi}_1$ (CV $\leq 0.20$ )	$\hat{\psi}_2$ (CV $\leq 0.20$ )
0.10	0.30	0.50	0.70	265	502
0.10	0.50	0.50	0.70	239	500
0.10	0.70	0.50	0.70	228	490
0.40	0.30	0.50	0.70	48	126
0.40	0.50	0.50	0.70	40	126
0.40	0.70	0.50	0.70	38	123
0.60	0.30	0.50	0.70	25	84
0.60	0.50	0.50	0.70	25	84
0.60	0.70	0.50	0.70	25	82
0.50	0.70	0.10	0.70	26	675
0.50	0.70	0.65	0.70	26	65
Mean minimum number of sites				90	260
Overall mean minimum number of sites				175	

As shown in Table 5, the mean minimum number of survey sites required for relatively precise and unbiased estimates of occupancy and successful reproduction, given the parameter values and model structure examined, was 175 sites visited four times each. The estimated number of sites required to meet benchmark precision values using a standard single-season, multistate occupancy design was consistently 2–3 greater for estimates of successful reproduction ( $\psi^2$ ) than for estimates of site occupancy ( $\psi^1$ ; Table 5). The mean minimum number of survey sites required to achieve a  $CV \leq 0.20$  was 90 sites for estimates occupancy, whereas a mean of 260 sites was required for relatively precise and unbiased estimates of reproduction. Note that these are conservative sample sizes that will provide more precise estimates if occupancy and detection probabilities are greater than those considered here. An example of the grid of territory-sized sampling units to survey occupancy, reproduction, and abundance of eagles is provided in Figure 10.

**Figure 10: Example of the Multistate Occupancy Sampling Design**



Under the proposed survey design, 175 focal sample sites (1,385-ha hexagons; shown in figure inset) are randomly selected from the grid of equal-sized hexagons overlaid on the DRECP area. Selection of focal sample sites can be stratified by habitat suitability if desired (i.e. to restrict surveys to areas with a greater likelihood of use by eagles). Each randomly selected sample site is then surveyed up to four times over the course of the breeding season (December–June) for evidence of occupancy and reproduction by territorial pairs of eagles, in addition to use by subadult eagles.

### 6.1.3 Standardized Survey Protocol

A detailed field protocol for collecting data on site occupancy, reproduction, and use of survey plots by golden eagles is provided in Appendix C. The protocol follows general recommendations by Driscoll (2010) and Pagel et al. (2010) for surveys of golden eagles, but has been modified to accommodate the proposed multistate-occupancy survey design (Wiens et al. 2015). The standardized survey protocol provides both general and specific guidance for implementing field surveys under the golden eagle monitoring plan. In general, surveys to detect occupancy, reproduction, and use of landscapes by eagles are conducted during the breeding season of each year (December–June).

## 6.2 Expected Conditions and Trends

Initial results from the predictive demographic model provided relevant expectations for population response of golden eagles, and their habitats, to planned increases in renewable energy development in the plan area. These expectations included:

- The local population of golden eagles will experience declines over the short term, caused by probable increases in subadult and adult fatalities associated with implementing renewable energy projects.
- In the long term, the local population is likely not self-sustaining as it is heavily reliant upon external recruitment from other areas to maintain numbers of breeding eagles.
- Quality of existing foraging habitats associated with future development focal areas will generally decline, but it remains unclear how mortality rates will be affected in these areas if use of these sites by individual eagles also declines as a result of decreased prey availability.

Observed estimates of population status and trend derived from newly collected survey data can be compared with expected values derived from the demographic model to strengthen the predictive capabilities of the model.

## 6.3 Reporting and Implementation Schedule

It is suggested that data collected on site occupancy, reproduction, survival, and annual rate of population change (based on occupancy parameters) be summarized annually. Estimating trends and status of population parameters will likely require a minimum of five years of data collection, regardless of the type of sampling methods used. Observed data on status and trend in the eagle population and their habitats coupled with projected population responses to disturbance (as predicted by the demographic model) will provide managers with feedback about existing conditions and allow comparisons with future expected conditions. Results of these comparisons will provide information that can be reviewed within a standardized framework to determine adequacy of management direction.

It is proposed that condition and trend in vegetation conditions and primary prey populations be estimated approximately 3–5 years after baseline models representing current conditions are acquired. Periodically monitoring status and trend of prey populations, for example, will allow

for estimates in the density and distribution of food resources to golden eagles and for relating such changes to disturbances or conservation actions. Trends in landscape disturbance conditions could be updated every 3–5 years for use in spatial demographic predictive modeling. Habitat trend results also provide a framework for testing the effectiveness of the DRECP in conserving broader ecosystem function, an added benefit of the monitoring design. Data from population monitoring and habitat (prey) assessments would be integrated in the refinement of the predictive demographic model so that researchers and land managers can map, conceptualize, and forecast potential population responses of golden eagles to planned renewable energy development, and associated management actions.

Dissemination of annual monitoring results may be accomplished through annual summary reports and periodic publications. An interpretive report of monitoring results of golden eagles and their habitats in the DRECP could be completed every five years. This report would provide decision makers with a scientifically credible evaluation of the state of golden eagle populations in the plan area, and if necessary, make recommendations for changes in monitoring, management, and mitigation strategies.



## GLOSSARY

Term	Definition
EPIC	Electric Program Investment Charge
Smart Grid	Smart Grid is the thoughtful integration of intelligent technologies and innovative services that produce a more efficient, sustainable, economic, and secure electrical supply for California communities.
Conceptual model	A representation of the set of causal relationships between factors that are believe to affect an at-risk species (Darst et al. 2013)
Conservation action	Interventions undertaken to reach conservation goals and objectives (Salafsky et al. 2008)
Demographic rates	The combination of population effects (mortality, reproductive output and immigration/emigration) with golden eagle life stages (juvenile, subadult, adult)
Model scenarios	Formal versioning of the data, recovery action tracking and user comments from system component tools, as well as system inputs and outputs for particular computational runs in program HexSim.
Sensitivity analysis	Sensitivity analysis is used to address which parameters of the demographic model (e.g., adult survival, reproduction, and emigration/immigration) are most responsible for system outcome uncertainty.
Threat	Naturally occurring or proximate human activities that have caused, are causing, or may cause the destruction, degradation, or impairment of a species (Salafsky et al. 2008).

## REFERENCES

- Albeke, S.E., Nibbelink, N.P. and Ben-David, M. 2015. Modeling behavior by coastal river otter (*Lontra Canadensis*) in response to prey availability in Prince William Sound, Alaska: a spatially-explicit individual-based approach. PLoS One 10:p.e0126208.
- Bailey, L.L., Hines, J.E., Nichols, J.D. and MacKenzie, D.I. 2007. Sampling design tradeoffs in occupancy studies with imperfect detection: examples and software. Ecological Applications 17:281–290
- Bailey, L. L., MacKenzie, D.I., and Nichols, J.D. 2014. *Advances and Applications of Occupancy Models*. Methods in Ecology and Evolution 5:1269-1279.
- Balbonin, J., Penteriani, V. and Ferrer, M. 2003. Variations in the age of mates as an early warning signal of changes in population trends? The case of Bonelli's eagle in Andalusia. Biological Conservation 109:417–423.
- Ball, L. C., P. F. Doherty Jr., and M.W. McDonald. 2005. *An Occupancy Modeling Approach to Evaluating a Palm Springs Ground Squirrel Habitat Model*. Journal of Wildlife Management 69:894–904.
- Besag, J., York, J., and Mollié, A. 1991. *Bayesian Image Restoration With Two Applications in Spatial Statistics*. Annals of the Institute of Statistical Mathematics 43:1–59.
- Bloom, P.H. and Clark, W.S. 2001. Molt and sequence of plumages of golden eagles and a technique for in-hand ageing. North American Bird Bander 26:97–116.
- Booms, T.L., Schempf, P.F., McCaffery, B.J., Lindberg, M.S. and Fuller, M.R. 2010. *Detection Probability of Cliff-Nesting Raptors During Helicopter and Fixed-Wing Aircraft Surveys in Western Alaska*. Journal of Raptor Research, 44:175-187.
- Braham, M.E., Miller, T.A., Duerr, A., Lanzone, M., Fesnock, A., Lapre, L., Driscoll, D. and Katzner, T.E. 2015. Home in the heat: dramatic seasonal variation in home range of desert golden eagles informs management for renewable energy development. Biological Conservation 186:225–232.
- Brown, L.H., and Watson, A. 1964. The golden eagle in relation to its food supply. Ibis 106:78–100.
- Brown, J.L. 2014. *Desert Eagle Conservation Strategy*. Report for the Department of Interior, United States Fish and Wildlife Service, Region 8. Reno, NV, USA.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., and Laake, J.L. 2005. Distance sampling. John Wiley and Sons, Ltd.

- Bruggeman, J.E., Swem, T., Andersen, D.E., Kennedy, P.L. and Nigro, D. 2016. Multi-season occupancy models identify biotic and abiotic factors influencing a recovering Arctic Peregrine Falcon *Falco peregrinus tundrius* population. *Ibis* 158:61–74.
- Burnham, K.P., and Anderson, D.R. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, Second Edition. Springer-Verlag, New York, New York, USA.
- Conservation Biology Institute (CBI). 2014. November 20. Alternative (December 2012 version) – Development Focus Areas, DRECP. Conservation Biology Institute, Corvallis, OR. (<http://databasin.org/search/#query=dfa&type=dataset>, accessed Sep17 2014).
- California Energy Commission. 2011. *Draft Preliminary Conservation Strategy, Desert Renewable Energy Conservation Plan*. Executive Summary (<http://www.drecp.org/draftdrecp/>; accessed Feb 10, 2014).
- California Energy Commission. 2014. *Draft Desert Renewable Energy Conservation Plan*. Executive Summary (<http://www.drecp.org/draftdrecp/>; accessed Feb 10, 2014).
- Conner, M.M., Keane, J.J., Gallagher, C.V., Munton, T.E. and Shaklee, P.A. 2016. *Comparing Estimates of Population Change From Occupancy and Mark–Recapture Models for a Territorial Species*. *Ecosphere* 7:51–64.
- Cressie, N., Calder, C.A., Clark, J.S., Ver Hoef, J.M., and Wikle, C.K. 2009. Accounting for uncertainty in ecological analysis: the strengths and limitations of hierarchical statistical modeling. *Ecological Applications* 19:553–570.
- Dali, D., and Madsen, L. 2011. *Models for Estimating Abundance From Repeated Counts of an Open Metapopulation*. *Biometrics* 67:577–587.
- Darst, C.R., Murphy, P.J., Strout, N.W., Campbell, S.P., Field, K.J., Allison, L. and Averill-Murray, R.C. 2013. *A Strategy for Prioritizing Threats and Recovery Actions for At-Risk Species*. *Environmental Management* 51:786–800.
- Doyle, J.M., Katzner, T.E., Bloom, P.H., Yanzhu, J., Wijayawardena, B.K., and DeWoody, J.A. 2014. The genome sequence of a widespread apex predator, the golden eagle (*Aquila chrysaetos*). *PLoS ONE* 9: e95599.
- Driscoll, D. 2010. *Protocol for Golden Eagle Occupancy, Reproduction, and Prey Population Assessment*. American Eagle Research Institute, Apache Jct., AZ USA. 55pp.
- Duerr, A.E., Miller, T.A., Duerr, K.L.C., Lanzone, M.J., Fesnock, A., and Katzner, T.E. 2015. Landscape-scale distribution and density of raptor populations wintering in anthropogenic-dominated desert landscapes. *Biodiversity and Conservation* 24:2365–2381.

- Dwyer, J.F., Harness, R.E., and Donohue, K. 2014. Predictive model of avian electrocution risk on overhead power lines. *Conservation Biology* 28:159–168.
- Ferrer, M. and Donazar, J.A. 1996. Density-dependent fecundity by habitat heterogeneity in an increasing population of Spanish imperial eagles. *Ecology* 77:69–74.
- Ferrer, M., Penteriani, V., Balbotin, J., and Pandolfi, M. 2003. The proportion of immature breeders as a reliable early warning signal of population decline: evidence from the Spanish Imperial Eagle in Doñana. *Biological Conservation* 114:463 – 466.
- Fielding, A., and Bell, J. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24:38–49.
- Franklin, J. 2010. Mapping species distributions: spatial inference and prediction. Cambridge University Press.
- Georgiou, T.T., and Lindquist, A. 2003. Kullback-leibler approximation of spectral density functions. *Transactions on Information Theory* 49:2910–2917.
- George, T. L., Thompson, J., and Nielson, R. 2014. *Golden Eagle Abundance in the Desert Renewable Energy Conservation Plan Area*. California Energy Commission. Publication number: CEC-500-2015-077.
- Good, R.E., Nielson, R.M., Sawyer, H. and McDonald, L.L. 2007. *A Population Estimate for Golden Eagles in the Western United States*. *Journal of Wildlife Management* 71:395–402.
- Grimm, V. 1999. Ten years of individual-based modelling in ecology: what have we learned and what could we learn in the future? *Ecological Modelling* 115:129–148.
- Hagen, C.A., Pavlacky Jr, D.C., Adachi, K., Hornsby, F.E., Rintz, T.J., and McDonald, L.L. 2016. Multiscale occupancy modeling provides insights into range-wide conservation needs of Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*). *The Condor* 118:597–612.
- Hall, L.S., Krausman, P.R. and Morrison, M.L. 1997. The habitat concept and a plea for standard terminology. *Wildlife Society Bulletin* 25:173–182.
- Heinrichs, J.A., D.J. Bender, D.L. Gummer, and N.H. Schumaker. 2010. *Assessing Critical Habitat: Evaluating the Relative Contribution of Habitats to Population Persistence*. *Biological Conservation* 143:2229–2237.
- Herring, G., C.A. Eagles-Smith, and Buck, J. 2017. Characterizing golden eagle risk to lead and anticoagulant rodenticide exposure: a review. *Journal of Raptor Research* 51:*in press*
- Hipkiss, T., Moss, E. and Hörnfeldt, B. 2014. Variation in quality of golden eagle territories and a management strategy for wind farm projects in northern Sweden. *Bird Study* 61:444–446.

- Holroyd, G., Knight, R., Lewis, S., Murphy, R., Pagel, J., Steenhof, K., and Whittington, D. 2010. A collaborative critique of the golden eagle's uncertain future in North America, in Minutes and notes of the North American golden eagle science meeting, 21 Sept. 2010, USGS Science Center, Fort Collins, Colorado, U.S. Fish and Wildlife Service, p. 1–28.
- Hunt, W.G. 1998. Raptor floaters at Moffat's equilibrium. *Oikos* 82:191–197.
- Hunt, W.G., 2002, *Golden Eagles in a Perilous Landscape: Predicting the Effects of Mitigation for Wind Turbine Blade-Strike Mortality*. Sacramento, California, Consultant Report to California Energy Commission under contract P500-02-043F, Public Interest Energy Research, 72 p.
- Hunt, W.G., J.D. Wiens, P.R. Law, M.R. Fuller, T.L. Hunt, D.E. Driscoll, and R. E. Jackman. 2017. Quantifying the demographic cost of human-related mortality to a raptor population. *PLoS One* 12(2): e0172232. doi:10.1371/journal.pone.0172232.
- Hylander, K. and Ehrlén, J. 2013. *The Mechanisms Causing Extinction Debts*. *Trends in Ecology and Evolution* 28:341–346.
- Inman, R. D., Nussear, K.E., Esque, T.C., Vandergast, A.G., Hathaway, S.A., Wood, D.A., Barr, K.R., and Fisher, R.N. 2014. Mapping habitat for multiple species in the desert southwest. Open-file report 2014-1134. U.S. Geological Survey.
- Kagan, R.A., Viner, T.C., Trail, P.W., and Espinoza, E.O. 2014. Avian Mortality at Solar Energy Facilities in Southern California: A Preliminary Analysis. Unpublished report to US National Fish and Wildlife Forensic Laboratory, Ashland.
- Katzner, T.E., Bragin, E.A. and Milner-Gulland, E.J. 2006. Modelling populations of long-lived birds of prey for conservation: a study of imperial eagles (*Aquila heliaca*) in Kazakhstan. *Biological Conservation* 132:322–335.
- Katzner T, Milner-Gulland, E.J., Bragin E. 2007. Using modeling to improve monitoring of structured populations: Are we collecting the right data? *Conservation Biology* 21:241–52.
- Katzner, T. E., J. A. R. Ivy, E. A. Bragin, E. J. Milner - Gulland, and J. A. DeWoody. 2011. Conservation implications of inaccurate estimation of cryptic population size. *Animal Conservation* 14:328–332.
- Katzner, T.E., D.M. Nelson, M.A. Braham, J.M. Doyle, N.B. Fernandez, A.E. Duerr, P.H. Bloom, M.C. Fitzpatrick, T.A. Miller, R.C. Culver, and L. Braswell. 2016. Golden Eagle fatalities and the continental-scale consequences of local wind-energy generation. *Conservation Biology* 31:406–415.
- Keitt, T.H., Lewis, M.A., and Holt, R.D. 2001. *Allee Effects, Invasion Pinning, and Species' Borders*. *The American Naturalist* 157:203–216.

- Kochert, M.N., and Steenhof, K. 2002. *Golden Eagles in the US and Canada: Status, Trends, and Conservation Challenges*. Journal of Raptor Research 36: 32–40.
- Kochert, M.N., Steenhof, K., McIntyre, C.L., and Craig, E.H. 2002. Golden eagle (*Aquila chrysaetos*), in Poole, A., and Gill, F. (eds.), *The Birds of North America*, no. 684, Philadelphia, The Birds of North America Inc., p. 1–44.
- Krausman, P.R. and Morrison, M.L. 2016. *Another Plea for Standard Terminology*. The Journal of Wildlife Management 80:1143–1144.
- Krauss, J., Bommarco, R., Guardiola, M., Heikkinen, R.K., Helm, A., Kuussaari, M., Lindborg, R., Öckinger, E., Pärtel, M., Pino, J. and Pöyry, J. 2010. Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. Ecology letters 13:597–605.
- Latta, B., and Thelander, C. 2013. Results of 2012 Golden Eagle Nesting Surveys of the California Desert and Northern California Districts. BioResource Consultants, Inc., Ojai, CA. Final Report to Bureau of Land Management, California State Office. Contract No. L11PXO2234. p. 13 and appendices
- Lee, D.E., and Bond, M.L. 2015. Previous year's reproductive state affects spotted owl site occupancy and reproduction responses to natural and anthropogenic disturbances. The Condor 118:747–765.
- Lehman, R.N., Kennedy, P.L., and Savidge, J.A. 2007. The state of the art in raptor electrocution research: a global review. Biological Conservation 136:159–174.
- Lehman, R.N., Savidge, J.A., Kennedy, P.L., and Harness, R.E. 2010. *Raptor Electrocution Rates for a Utility in the Intermountain Western United States*. Journal of Wildlife Management 74:459–470.
- Lobo, J. M., Jiménez-Valverde, A., and Real, R. 2008. AUC: a misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography 17:145–151.
- Lint, J.B, Noon, B.R., Anthony, R.G., Forsman, E.D., Raphael, M.G., Collopy, M., and Starkey, E. 1999. *Northern Spotted Owl Effectiveness Monitoring Plan for the Northwest Forest Plan: U.S. Forest Service*, General Technical Report PNW-GTR-440.
- Longshore, K.M, Esque, T.C., Nussear, K.E., Johnson, D.R., and Simes, S.M. 2017. *An Assessment of Food Habits, Prey Availability, and Nesting Success of Golden Eagles within the Desert Renewable Energy Conservation Plan Area*. California Energy Commission. Publication Number 500–1216.

- Lovich J.E. 2015. Golden eagle mortality at a utility-scale wind energy facility near Palm Springs, California. *Western Birds* 46:76–80.
- MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Andrew Royle, J. and Langtimm, C.A. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83:2248–2255.
- MacKenzie, D.I., Nichols, J.D., Hines, J.E., Knutson, M.G. and Franklin, A.B. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology* 84:2200–2207.
- MacKenzie, D.I. 2005. *What are the Issues with Presence–Absence Data for Wildlife Managers?*. *Journal of Wildlife Management* 69:849–860.
- MacKenzie, D.I., Nichols, J., Sutton, N., Kawanishi, K. and Bailey, L.L. 2005. Improving inferences in population studies of rare species that are detected imperfectly. *Ecology* 86:1101–1113.
- MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L.A., and Hines, J.E. 2006, *Occupancy estimation and modeling: San Diego, California*, Academic Press.
- MacKenzie, D.I., J.D. Nichols, M.E. Seamans, and R.J. Gutierrez. 2009. Dynamic models for problems of species occurrence with multiple states. *Ecology* 90:823–835.
- Madsen, S., Evans, D., Hamer, T., Henson, P., Miller, S., Nelson, S.K., Roby, D. and Stapanian, M. 1999. *Marbled Murrelet Effectiveness Monitoring Plan for the Northwest Forest Plan*.
- Marcot B.G., Singleton P.H., Schumaker N.H. 2015. Analysis of sensitivity and uncertainty in an individual-based model of a threatened wildlife species. *Natural Resource Modeling* 28:37–58.
- Marques, A.T., Batalha, H., Rodrigues, S., Costa, H., Pereira, M.J.R., Fonseca, C., Mascarenhas, M., and Bernardino, J. 2014. Understanding bird collisions at wind farms: an updated review on the causes and possible mitigation strategies. *Biological Conservation* 179:40–52.
- Martin, J., McIntyre, C.L., Hines, J.E., Nichols, J.D., Schmutz, J.A., and MacCluskie, M.C. 2009, Dynamic multistate site occupancy models to evaluate hypotheses relevant to conservation of golden eagles in Denali National Park, Alaska. *Biological Conservation* 142:2726–2731.
- McIntyre, C.L. and Schmidt, J. 2012. Ecological and environmental correlates of territory occupancy and breeding performance of migratory golden eagles *Aquila chrysaetos* in interior Alaska. *Ibis* 154:124–135.

- Millsap, B.A., Zimmerman, G.S., Sauer, J.R., Nielson, R.M., Otto, M., Bjerre, E., and Murphy, R. 2013. *Golden Eagle Population Trends in the Western United States: 1968 – 2010*. Journal of Wildlife Management 77:1436–1448.
- Millsap, B.A., Harmata, A.R., Stahlecker, D.W. and Mikesic, D.G. 2014. Natal dispersal distance of Bald and golden eagles originating in the coterminous United States as inferred from band encounters. Journal of Raptor Research 48:13–23.
- Millsap, B.A., Grubb, T.G., Murphy, R.K., Swem, T., and Watson, J.W. 2015. Conservation significance of alternative nests of golden eagles. Global Ecology and Conservation 3:234–241.
- Morrison, M. L., Marcot, B.G., and Mannan, R.W. 2006. *Wildlife-Habitat Relationships: Concepts and Applications*. 3rd edition. Island Press, Washington, D.C.
- Mulder, B.S., Noon, B.R., Spies, T.A., Raphael, M.G., Palmer, C.J., Olsen, A.R., Reeves, G.H. and Hartwell Jr, H. 1999. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. General Technical Report PNW-GTR-437. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 138 p.
- Munns Jr, W.R. 2006. Assessing risks to wildlife populations from multiple stressors: overview of the problem and research needs. Ecology and Society 11:1–23.
- Murphy, R.K., J.R. Dunk, B. Woodbridge, D.W. Stahlecker, D.W. Laplante, B.A. Millsap, and K.V. Jacobson. 2017. First-year dispersal of golden eagles from natal areas in the southwestern United States and implications for second-year settling. Journal of Raptor Research 51:*in press*
- Nelson, D.M., Braham, M., Miller, T.A., Duerr, A.E., Cooper, J., Lanzone, M., Lemaître, J. and Katzner, T.E. 2015. Stable hydrogen isotopes identify leapfrog migration, degree of connectivity, and summer distribution of golden eagles in eastern North America. The Condor 117:414–429.
- New, L., Bjerre, E., Millsap, B., Otto, M.C., and Runge, M.C. 2015. A collision risk model to predict avian fatalities at wind facilities: an example using golden eagles, *Aquila chrysaetos*. PloS one 10:p.e0130978.
- Newton, I. 1992. Experiments on the limitation of bird numbers by territorial behaviour. Biological Reviews 67:129–173.
- Nichols, J.D., Hines, J.E., MacKenzie, D.I., Seamans, M.E., and Gutiérrez, R.J. 2007. Occupancy estimation with multiple states and state uncertainty. Ecology 88:1395-1400
- Noon, B.R., Bailey, L.L., Sisk, T.D., and McKelvey, K.S. 2012. Efficient species-level monitoring at the landscape scale. Conservation Biology 26:432–441.



- Olson, L.E., Oakleaf, R.J., Squires, J.R., Wallace, Z.P. and Kennedy, P.L. 2015. Nesting pair density and abundance of ferruginous hawks (*Buteo regalis*) and golden eagles (*Aquila chrysaetos*) from aerial surveys in Wyoming. *Journal of Raptor Research* 49:400–412.
- Pagel, J. E., Whittington, D.M., and Allen, G.T. 2010. Interim golden eagle inventory and monitoring protocols and other recommendations. Division of Migratory Bird Management, US Fish and Wildlife Service.
- Pagel, J.E., Kritz, K.J., Millsap, B.A., Murphy, R.K., Kershner, E.L., and Covington, S. 2013. Bald eagle and golden eagle mortalities at wind energy facilities in the contiguous United States. *Journal of Raptor Research*, 47:311–315.
- Pellet, J. and Schmidt, B.R. 2005. Monitoring distributions using call surveys: estimating site occupancy, detection probabilities and inferring absence. *Biological Conservation*, 123:27–35.
- Poessel, S.A., Bloom, P.H., Braham, M.A., and Katzner, T.E. 2016. Age- and season-specific variation in local and long-distance movement behavior of golden eagles. *European Journal of Wildlife Research* 62:1–17.
- Resano-Mayor, J., Real, J., Moleón, M., Sánchez-Zapata, J.A., Palma, L. and Hernández-Matías, A. 2016. Diet–demography relationships in a long-lived predator: from territories to populations. *Oikos* 125:262–270.
- Rossman, S., Yackulic, C.B., Saunders, S.P., Reid, J., Davis, R. and Zipkin, E.F. 2016. Dynamic N-occupancy models: estimating demographic rates and local abundance from detection-nondetection data. *Ecology* 97:3300–3307.
- Rudnick, J.A., Katzner, T.E., Bragin, E.A., Rhodes, Jr., O.E., and DeWoody, J.A. 2005. Using naturally shed feathers for individual identification, genetic parentage analyses, and population monitoring in an endangered Eastern imperial eagle (*Aquila heliaca*) population from Kazakhstan. *Molecular Ecology* 14:2959–2967.
- Rudnick, Katzner, T.E., Bragin, E.A., and DeWoody, J.A. 2008. A non-invasive genetic evaluation of population size, natal philopatry, and roosting behavior of non-breeding eastern imperial eagles (*Aquila heliaca*) in central Asia. *Conservation Genetics* 9:667–676.
- Runge, J.P., Runge, M.C. and Nichols, J.D. 2006. The role of local populations within a landscape context: defining and classifying sources and sinks. *The American Naturalist*, 167:925–938.
- Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H., Collen, B.E.N., Cox, N., Master, L.L., O'connor, S. and Wilkie, D. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. *Conservation Biology* 22:897–911.

- Sánchez-Zapata, J.A., Calvo, J.F., Carrette, M., and Martínez, J.E. 2000. Age and breeding success of a Golden Eagle *Aquila chrysaetos* population in southeastern Spain. *Bird Study* 47:235–237.
- Schumaker, N.H, Brookes, A., Dunk, J.R., Woodbridge, B., Heinrichs, J.A., Lawler, J.J., Carroll, C., and LaPlante, D. 2014. Mapping sources, sinks, and connectivity using a simulation model of northern spotted owls. *Landscape Ecology* 29:579–592.
- Schmolke, A., Thorbek, P., DeAngelis, D.L., and Grimm, V. 2010. Ecological models supporting environmental decision making: a strategy for the future. *Trends in Ecology and Evolution* 25:479–486.
- Skipper, B.R., Boal, C.W., Tsia, J., and Fuller, M.R. 2017. Assessment of frequency and duration of point counts when surveying for golden eagle presence. *Wildlife Society Bulletin* 41:212–223.
- Spaul, R.J. and Heath, J.A. 2016. Nonmotorized recreation and motorized recreation in shrub-steppe habitats affects behavior and reproduction of golden eagles (*Aquila chrysaetos*). *Ecology and Evolution* 6:8037–8049.
- Steenhof, K., Kochert, M.N., and Doremus, J. H. 1983. Nesting of subadult golden eagles in southwestern Idaho. *The Auk*:743–747.
- Steenhof, K., Kochert, M.N., and McDonald, T.L. 1997. Interactive effects of prey and weather on golden eagle reproduction. *Journal of Animal Ecology* 66:350–362.
- Steenhof, K., and I. Newton. 2007. Assessing nesting success and productivity. *in* D.E. Bird and K.L. Bildstein (eds.), *Raptor research and management techniques*: Blaine, Washington, Hancock House Publishers, p. 181–192.
- Steenhof, K., Brown, J.L., and Kochert, M.N. 2014. Temporal and spatial changes in golden eagle reproduction in relation to increased off highway vehicle activity. *Wildlife Society Bulletin* 38:682–688.
- Stenglein, J.L., Gilbert, J.H., Wydeven, A.P. and Van Deelen, T.R. 2015. An individual-based model for southern Lake Superior wolves: A tool to explore the effect of human-caused mortality on a landscape of risk. *Ecological Modelling* 302:13–24.
- Soutullo A., Urios V., Ferrer M., Peñarrubia S.G. 2006. Dispersal of golden eagles *Aquila chrysaetos* during their first year of life. *Bird Study* 53:258–264.
- Tack, J.D. 2016. Guiding conservation of golden eagle populations in light of expanding renewable energy development: a demographic and habitat-based approach. Doctoral dissertation, Colorado State University, Fort Collins, Colorado.

- Tuma, M.W., Millington, C., Schumaker, N. and Burnett, P. 2016. *Modeling Agassiz's Desert Tortoise Population Response to Anthropogenic Stressors*. The Journal of Wildlife Management 80:414–429.
- Turner M.G., Arthaud G.J., Engstrom R.T., Hejl S.J., Liu J, Loeb S, McKelvey K. 1995. Usefulness of spatially explicit population models in land management. *Ecological Applications* 1:12–6.
- U.S. Fish and Wildlife Service [USFWS]. 2012. Designation of revised critical habitat for the Northern Spotted Owl, Final Rule. Federal Register. Vol. 77: 71876–72068.
- U.S. Fish and Wildlife Service [USFWS]. 2013. Eagle conservation plan guidance: module 1 — Land-based wind energy, version 2: U.S. Department of the Interior, Division of Migratory Bird Management.
- U.S. Fish and Wildlife Service [USFWS]. 2016. Bald and golden eagles: Population demographics and estimation of sustainable take in the United States: 2016 update. Division of Migratory Bird Management, Washington D.C., USA.
- Walston, L.J., Jr, Rollins, K.E., LaGory, K.E., Smith, K.P., and Meyers, S.A. 2016. A preliminary assessment of avian mortality at utility-scale solar energy facilities in the United States. *Renewable Energy* 92:405–414.
- Watson, J., 2010. *The Golden Eagle*, second edition. Yale University Press, New Haven and London.
- Whitfield, D.P., Fielding, A.H., McLeod, D.R.A., and Haworth, P.F. 2004. Modelling the effects of persecution on the population dynamics of golden eagles in Scotland. *Biological Conservation* 119:319–333.
- Wiens, J.D., Kolar, P.S., Fuller, M.R., Hunt, W.G., and Hunt, T. 2015, Estimation of occupancy, breeding success, and predicted abundance of golden eagles (*Aquila chrysaetos*) in the Diablo Range, California, 2014. U.S. Geological Survey Open-File Report 2015-1039, 23 p., <http://dx.doi.org/10.3133/ofr20151039>.
- Wikle, C. K. 2003. Hierarchical models in environmental science. *International Statistical Review* 71:181–199.

# **APPENDIX A:**

## **Report on the DRECP Golden Eagle Monitoring Plan Meeting**

### **1.0 Introduction to the Meeting**

On Nov 20 – 21, 2013, representatives of management and regulatory agencies responsible for conservation of golden eagles in the Desert Renewable Energy Conservation Plan (DRECP) area met with scientists specializing in golden eagle ecology and survey methods to clarify objectives and expected uses of monitoring data and to determine specific options and tools available to meet the data needs. The information shared at this meeting will guide the development of a survey and monitoring protocol designed to provide information required to promote effective golden eagle conservation and compatible renewable energy development within the DRECP area. This information will be especially critical in determining whether regulatory requirements and goals of the conservation plan are being met.

### **2.0 Meeting Objectives and Mechanics**

The stated overall goal of the meeting was to determine the objectives and scientific strategy for a standardized protocol for surveying and monitoring golden eagle populations in areas covered by the DRECP.

Specific objectives of the meeting were to:

1. List objectives and expected uses of golden eagle survey and monitoring data.
2. Share information about the ecology, behavior, population status, and current monitoring tools for local populations of golden eagles.
3. Share information about the benefits, constraints, and costs associated with current survey and monitoring tools used to track populations of golden eagles.
4. Discuss monitoring goals given data limitations and scientific objectives.
5. Discuss and prioritize future funding needs and opportunities.

The meeting was attended by seven representatives of the U.S. Fish and Wildlife Service (USFWS), 11 representatives of the U.S. Geological Survey (USGS), three from the California Energy Commission (CEC), three from universities, two from California Department of Fish and Wildlife (CDFW), one each from the Bureau of Land Management (BLM) and Western EcoSystems Technology (WEST) Inc., and two facilitators (Table A.1).

**Table A.1: List of Participants of the DRECP Golden Eagle Monitoring Plan Workshop, 2013**

Jim Nelson, Facilitator	Nelson Facilitation,
Heather Beeler, notes	U.S. Fish and Wildlife Service
Amedee Brickee	U.S. Fish and Wildlife Service
Sue Phillips	U.S. Geological Survey
Sue Jones	U.S. Geological Survey
Elliot Chasin	California Department of Fish and Wildlife
Brian Woodbridge	U.S. Fish and Wildlife Service
Ben Skipper	Texas Tech University
Clint Boal	U.S. Geological Survey
Emily Bjerre	U.S. Fish and Wildlife Service
Dan Cox	U.S. Fish and Wildlife Service
Leslie New	U.S. Geological Survey
Jessie Brown	University of Nevada, Reno
Misa Milliron	California Energy Commission
Joe O'Hagan	California Energy Commission
David Wiens	U.S. Geological Survey
Mark Fuller	U.S. Geological Survey
Ryan Nielsen	WEST, Inc
Todd Katzner	West Virginia University
John Sauer	U.S. Geological Survey
Guthrie Zimmerman	U.S. Fish and Wildlife Service
Anwar Ali	California Energy Commission
Jeff Tracey	U.S. Geological Survey
Carrie Battistone	California Department of Fish and Wildlife
Brian Millsap	U.S. Fish and Wildlife Service
Amy Fesnock	Bureau of Land Management
Steve Schwarzbach	U.S. Geological Survey
Todd Esque	U.S. Geological Survey
Ken Nussear	U.S. Geological Survey

In the first part of the meeting, the facilitator moderated presentations given by representatives of the USFWS (both regionally and nationally), CDFW, CEC, and BLM. Presenters described data needs and how their agencies planned to use golden eagle monitoring data to meet objectives of the conservation plan. Presentations from agency representatives were followed by a series of presentations from scientists involved in current research on golden eagles in the region. Scientists described the current status of monitoring efforts, the types of surveys currently being used to address research questions, and information about movements and ecology of golden eagles in desert regions of southern California. In the second portion of the

meeting, the facilitator led a focused discussion among agency representatives and researchers to clarify and prioritize monitoring goals for the DRECP.

### **3.0 Meeting Outputs**

#### **3.1 Presentations of Agency Uses of Monitoring Data**

##### *U.S. Fish and Wildlife Service-Region 8*

- The USFWS strives to meet the conservation standard for stable or increasing breeding golden eagle populations over Eagle Management Unit Scales, which in this case are the Bird Conservation Regions (BCRs; DRECP area overlaps BCR 32 and 33).
- The primary need for permitting of renewable energy projects under the DRECP is a monitoring plan that will track golden eagles in the DRECP area and inform land managers about the Eagle population status. Monitoring protocols should achieve a high degree of certainty as to whether the population is stable, increasing, or decreasing. The USFWS realizes that the DRECP area may not be a biologically relevant scale for golden eagles, but monitoring at this scale is needed for the purposes of meeting all the REAT (Renewable Energy Action Team) agencies regulatory needs.
- A secondary need is the development of a monitoring plan that can be used in conjunction with current USFWS monitoring efforts to track population trends at regional and national scales. The current Eagle Management Scale is being re-evaluated by the USFWS as part of their efforts to revise the 2009 Take Rule.

##### *U.S. Fish and Wildlife Service-National Office*

- USFWS National Office representatives described how current golden eagle population estimates derived from the WEST Inc. aerial surveys do not take uncertainty into account, although they are working to use Breeding Bird Survey data to address this. New monitoring plans should include estimates of uncertainty, and help verify assumptions made in utilizing national-scale estimates. Essentially, a test of the scaling factors used to step down from national to local populations is needed.
- Benchmarks for local area population status are desired because any take must be offset by mitigation (i.e., no net loss). Monitoring should help define harvestable take thresholds and should consider seasonal changes in populations because harvest rate estimates are based on summer population measures.
- Monitoring data should be applicable across multiple geographic scales, as DRECP decisions will affect populations outside of the DRECP area, so local and national need to mesh. There is not much room for take within the small populations of the DRECP, so the effect of poor precision of BCR-scale or other broader geographic population estimates will need to be understood. Data is needed also on a finer demographic scale, for instance nesting success and site occupancy.

#### *California Department of Fish and Wildlife*

- The CDFW representative described how take permits need to be proportional to impact, and take into account the goal of sustaining and restoring impacted populations.
- The state wants to see a suite of monitoring scenarios and options that could be enacted based on different funding levels. Such options should include population and demographic components, as both numerically and demographically stable populations are desired. Monitoring options should build on existing efforts, and coordinate with other working groups, and must feature adaptive management components.

#### *Bureau of Land Management*

- The BLM representative emphasized the need for a useful, practical, and tiered or nested monitoring system. More than one monitoring plan would be needed, and different options for monitoring and associated pros and cons are desired.
- Monitoring must define demographic thresholds and detect population declines. BLM wants to know if golden eagles in the desert are self-sustaining, both in terms of absolute numbers of birds, and in terms of demographic stability.
- Information is needed on the effects of individual energy projects on eagles to understand cumulative impacts of BLM management decisions. Wildlife and Wildlife Habitat Management is one of the directives under the multiple use mandate so the BLM must ensure that, within other management-use decisions, wildlife habitat is sufficiently available and that wildlife populations thrive (not just subsist).
- BLM is in the position to require more science and monitoring from projects they approve, and to require more mitigation if the science supports it.

#### *California Energy Commission*

- The Energy Commission representative spoke of their need to understand the conditions for take in permanent concentrated solar and geothermal projects. Monitoring data must support take decisions, and inform adaptive management.

### **3.2 Presentations of Science Information on DRECP golden eagle Status**

*Mark Fuller* (USGS) described USGS efforts to pull together all known survey data available for DRECP golden eagles, including information from BBS, Christmas bird counts, and BLM surveys. Challenges to understanding current methods include the different behaviors and habitat use by different life stages (breeding adults, non-breeding adults, subadults and juveniles), and how these differences may influence monitoring at local and BCR scales, which these wide-ranging birds readily cross.

*Todd Katzner* (University of West Virginia) described a body of research on golden eagles that provides relevant information on population ecology and effects of human development. Results showing the home range size, movement behavior, and habitat use of territorial and

non-territorial adults in the DRECP area were presented, along with information on the genetic uniqueness of these eagles. Results also emphasized the importance of high-elevation forests to eagles that are adjacent to DRECP lands. Additional work on origins of golden eagles killed in the Altamont Wind Resource Area was presented.

*Ryan Nielsen* (WEST Inc.) shared information about aerial surveys aimed at estimating the abundance of golden eagles (including non-breeders, floaters, and juveniles) in the DRECP area. A late summer, post-fledging aerial survey occurred in August 2013, and results were presented. Aerial surveys followed protocols developed for western-wide surveys, although characteristics particular to the region, such as the significant amount of “no flight” Department of Defense (DOD) lands, high density of transects, and high temperatures may have influenced the surveys. As expected from other WEST Inc. surveys, few eagles were seen in summer. A winter survey was planned for December, and full analysis of the results will follow. A preliminary conclusion from the first attempt to estimate abundance of golden eagles via aerial surveys was that the method provided insufficient numbers of detections for reliable estimation of abundance.

*Clint Boal* (USGS) described an ongoing joint USGS-USFWS research effort that seeks to inform golden eagle survey and monitoring protocol development. This project aims to develop a decision tool that will facilitate development of location specific protocols for golden eagle surveys and monitoring. These protocols would include surveys of a frequency and duration that would optimize estimations of detection probability and occupancy, while minimizing survey costs.

*David Wiens* (USGS) described joint USGS/Peregrine Fund research on surveys of site occupancy and nesting success of golden eagles in the Diablo Mountains. In this ongoing research, survey methods are being tested that provide information on factors influencing occurrence, nesting success, and detection probabilities of territorial pairs of golden eagles at broad spatial scales. This research is based in central California (northern Diablo Mountains), but can provide important baseline information for future comparisons with similar data gathered in the DRECP area.

### **3.3 Discussion Outcomes**

List of monitoring objectives derived from group discussion

1. Detect population trends over time.
2. Measure project-level and plan-level lethal and sub lethal effects.
3. Gather information that helps inform reasons for population change.
4. Parameterize demographic model.
5. Inform adaptive management; this will need multiple data sets and models.
6. Identify, quantify, explain, and model change; then test for change and refine the model.



7. Focus on populations, demography, and habitat change, minimizing cost and effort.
8. Measure effectiveness of mitigation measures and habitat enhancement efforts.
9. Incorporate the land treatment database.

#### List of data needs

1. Occupancy, including territories and probability of detection.
2. Information on the quality of data collected.
3. Mortality monitoring, including project by project “requirements,” and different requirements among relevant agencies.
4. Information about indirect and cumulative effects; for instance, as habitat is converted, is there a population effect? Are there carrying capacity effects? Can causes of habitat and population change be identified? What is the likelihood of long-term sustainability?
5. Data for modeling to predict population fate.
6. What is the effect of the plan on population trends and occupancy? Can plan implementation be improved?
7. Baseline data; on- and off-site, pre- and post-development.
8. Data for adaptive management. Long-term trend data has high uncertainty, which must be measured. The scale and timeframe of adaptive management decisions will inform data needs.
9. Demography, including the relative contribution of different impacts.

#### **Potential funding sources for monitoring**

USGS and CEC have provided the funding for this meeting, and for the development and publication of a protocol document. However, implementation of the survey plan is not funded. In the future, golden eagle monitoring will be funded primarily through fees collected from project developers. In the early years of the DRECP, the stream of funding may trickle in, as projects are approved and implemented. To procure additional funding to support future monitoring, the group said that if the federal agencies are united behind a single course of action, obtaining more funding would be likely. CEC Public Interest Energy Research (PIER) Grants may be one source worth exploring, as are CDFW Section 6 Grants, although they take time and opportunities are limited. Industry sources, such as American Wind Energy Association (AWEA), California Wind Energy Association (CalWEA), American Wind Wildlife Institute (AWWI) are also possibilities. BLM may have 2014 funding for golden eagle monitoring.

## 4.0 Conclusions

Although an array of potential uses for monitoring data were discussed, the group did not reach a consensus answer to the question of exactly what type of information a monitoring protocol should provide. After vigorous discussion, a survey protocol that led to a scalable parameterized demographic model seemed to rise to the top of options that may meet the greatest number of the expressed needs. Such a model, which would be required to predict how golden eagle populations may respond to renewable energy development projects in the DRECP area, would include both adult and pre-adult survivorship and estimates of reproductive output of territorial pairs, to estimate and predict long- and short-term rate of population change. However, it remained unclear at the end of the meeting if a single protocol should be developed, or if the best outcome for the USGS would be to provide a document that outlines a number of available survey and monitoring options, including their costs and benefits in terms of scientific understanding and funding requirements.

Of the stated objectives for the meeting, the following were met:

- List objectives for and uses of golden eagle monitoring data.
- Share information about local golden eagle populations, including biology, population status and conditions.
- Discuss future funding needs and opportunities.

These objectives were not completely met:

- Share information about the specific constraints and opportunities of known golden eagle monitoring protocols and tools.
- Discuss monitoring goals given data uses and scientific objectives.
- Prioritize actions to match funding, and vice versa.

Although there was not a clear or unanimous consent on the uses for monitoring data, or on the direction the USGS should take, there was general approval that USGS should proceed with the development of a demographic model, along with a description of available survey and monitoring tools required to parameterize the model. Once completed, this will provide insights to the value of information on different parameters, and once shared with the participating science and management agencies, could facilitate development of specific monitoring objectives and inform next steps.

## APPENDIX B:

### Baseline Parameter Values of the Golden Eagle Predictive Demographic Model.

Event category	Parameter	Stage Class <sup>a</sup>	Value
Territory prospecting and establishment	Minimum nesting habitat score to establish territory	S3, S4, A	18
	Target nesting habitat score	S4, A	40
	Maximum area explored to meet target	S4, A	50 km <sup>2</sup>
		S3	200 km <sup>2</sup>
	Dispersal distance (if nesting habitat score < 18)	S3, S4, A	54 – 107 km
	Maximum number of dispersal moves if unsuccessful	S4, A	5
		S3	3
Foraging and resource acquisition	Home range size	S4, A	≤ 500 km <sup>2</sup>
		J, S2, S3	600 – 800 km <sup>2</sup>
	Prey resource acquisition target	A	400
		S2, S3, S4	350
		J	300
	Prey resource class (% of resource target acquired in home range)	J, S2, S3, S4, A	Low (< 40%)
			Medium (40 – 89%)
			High (≥ 90%)
Reproduction	Expected fecundity (mean, min, and max values of		

Poisson distribution)	A	0.40, 0, 3	
		S4	0.17, 0, 3
	Prey resource class coefficient	S4, A	Low (multiply expected by 0.75)
			Medium (multiply expected by 1.00)
			High (multiply expected by 1.25)
	OHV exposure (% overlap of OHV area and territory)	S4, A	≥ 85%
Dispersal movements	Juvenile dispersal (first-year movement distance)	J	90 – 175 km
	Emigration (parameterized as additional mortality)	J, S2	0.10 – 0.12
	Immigration (annual introductions)	Random (1 – 5 years old)	15 individuals per year
Survival	Survival rates by stage and prey resource class	J	Low (0.70)
			Medium (0.74)
			High (0.80)
		S2	Low (0.70)
			Medium (0.77)
			High (0.80)
		S3, S4	Low (0.82)
			Medium (0.85)
			High (0.87)
		A	Low (0.85)
			Medium (0.87)

<sup>a</sup>Stage classes included juveniles (J), second-year subadults (S2), third-year subadults (S3), fourth-year subadults (S4), and adults (eagles ≥5 years old; A).

# **APPENDIX C:**

## **A Standardized Survey Protocol for Gathering Data on Site Occupancy, Reproduction, and Use of Landscapes by Golden Eagles**

### **Background**

This protocol provides both general and specific direction for implementing field surveys of golden eagles (GOEA) in the northern Diablo Mountains of central California. The survey design uses a multistate occupancy framework (Nichols et al. 2007, MacKenzie et al. 2009) as a means of drawing inferences about GOEA occurrence and nesting success at broad spatial scales. Under this sampling framework, areas targeted for repeated surveys (i.e.; potential territories or sites) are selected randomly from a grid of equal sized (e.g., 1,300 ha) hexagonal sample plots overlaid on the study area. Sample plots approximate the size of a golden eagle territory. At each survey, each site is characterized as being in 1 of 3 possible observation states: 1=no GOEA pair detected, 2=GOEA pair detected but no evidence of successful nesting, and 3=GOEA pair detected with evidence of successful nesting ( $\geq 1$  young fledged). Inferences about occupancy and reproduction account for imperfect detection probabilities that can vary over time and among breeding and non-breeding behavioral “states” of territorial pairs. As this survey approach is implemented, testing will be conducted to address uncertainties related to the surveys and updated guidance will be issued as new information becomes available.

Note that the methods outlined below can be applied towards surveys conducted at breeding territories historically used by golden eagles, or surveys conducted at randomly placed sampling units.

### **Survey Objectives**

In general, the primary objectives of surveys of golden eagles conducted under the multistate occupancy design are to:

1. Establish the presence or absence of breeding or non-breeding eagles
2. Establish the number of individual eagles using given site (i.e., territory or sample plot)
3. Establish reproductive state of a given site (i.e., nesting or not nesting)
4. Determine reproductive output at a given site (i.e., number of young fledged)
5. Determine age-class of individual eagles observed

**Table D.1: Breeding Chronology of Golden Eagles in the DRECP Area, California**

<b>Breeding Period</b>	<b>Timeframe</b>
Courtship	December – February
Egg laying	Peaks in last half of February (median date = Feb 20 <sup>th</sup> )
Incubation	ca. 43 days
Nestlings/fledglings	Late March to mid-June
Time to fledging	ca. 63-70 days (note: young may fledge in May)

**Table D.2. Timing of Visits to Determine Occupancy Status and Reproduction of Territorial Pairs of Golden Eagles**

<b>Pair Occupancy Status</b>	<b>Nesting Status</b>	<b>Reproduction (Number of Young Fledged)</b>
15 December – 1 July	1 March – 31 May	1 May – 1 July

## Survey Methods

**Note:** The below survey methods have been modified from Driscoll (2010) and Pagel et al. (2010) to accommodate the multistate occupancy survey design described by Wiens et al. (2015). Survey methods are described specifically for ground-based surveys of occupancy and nesting status. Under a repeated-visit dynamic occupancy design, aerial-based surveys (e.g., George et al. 2014) may also be included because differences between survey methods in detection probabilities of eagles, their nests, and young can be accounted for in data analyses.

*Establishing the Survey Area and Observation Points (OP's):* Surveys of golden eagles will be conducted within established 1,300 ha survey hexagons (hereafter referred to as “sites”) during 4–5 repeated visits during the breeding season (15 December – 1 July).

- The objective of a complete survey is to conduct a thorough search of the entire site in a single visit. If complete coverage of a site is not possible during a single visit, observers should report the approximate percentage of the hexagon that was successfully searched and attempt to return to the site to complete the survey the following day (or soon thereafter). Follow-up visits to an area may be required when weather interferes with a survey or immediate verification of a golden eagle activity center is required.
- Initial surveys of each site will take place during the courtship stage of breeding, or pre-nesting period (Jan 1 – Feb 28), when displays by territorial pairs are most conspicuous. Median egg-laying date is in the third week of February.
- Subsequent surveys of each site should be at least 10 days apart, but may be flexible for occupied territories to coincide with the timing of nesting stages.

- Observers will search for golden eagles from 1–4 Observation Points (OPs) that provide as complete coverage of the site as possible. OPs should be established on hilltops or high ridges that provide sweeping views of the landscape within the focal site. Note, in some cases OPs may be located outside of the focal site boundary to provide better coverage. Observers should record GPS coordinates for all OPs.
- Observations of nests from OPs should be 400–800-m away, or at a distance necessary to avoid disturbing nesting eagles.
- When an OP is initially approached, it is important to scan the area beforehand so that unknown locations of nesting eagles are not inadvertently disturbed. Be aware that if disturbed, golden eagles may depart the area without being seen.
- Observers should continue searches while traveling between established OPs to help ensure the site is adequately searched.

*Duration of Surveys:* Observation periods for each site should be limited to  $\leq 4$  hours total. Note that surveys may be shortened in cases in which pair occupancy and/or nesting status is determined quicker.

- All surveys will be conducted between 1 hour after sunrise and 1 hour before sunset to optimize detectability of perching and soaring golden eagles.
- Surveys should not be conducted in extreme weather conditions where observations of adults might be difficult or eggs/nestlings would be exposed to heat/cold if disturbed.

*Conducting Searches from OP's:* Once a survey is initiated at an OP within a site, observers will scan for golden eagles with binoculars and spotting scopes. If  $>1$  OPs are required to provide complete coverage of a site, observers should remain at each OP for 1–2 hours each.

- Observers will record all golden eagle and nest locations on data forms (see below). Observers will also map the general locations of perches, territorial displays, flight paths, or other activities observed on topographic maps of sites. Not all activities need to be mapped, only those that provide information on the locations of an individual or pair activity center
- Observers should attempt to record detections (but not specific locations) of other large raptor species (*Buteo* hawks, great-horned owls, prairie falcons, peregrine falcons, etc.), but only when it does not interfere with determining occupancy and nesting status of golden eagles that are present.

### **Determining Site-occupancy, Reproductive Output, and Age of Individual Eagles**

*Occupancy Status:* A sampling unit will be determined to be occupied during a single visit if at least one of the following is recorded:

- One or more golden eagles are seen engaging in territorial display (i.e. undulating flight behavior) or courtship behavior (i.e. pair soaring, carrying nesting material, decorating nests, or copulating) at a location estimated within the established site.
- Presence of recently decorated golden eagles nests with or without adults present also indicates the sampling unit is occupied (Steenhof and Newton 2007).
  - Be aware that subadults and adult “floaters” may also display without holding a territory.

*Nesting Status and Reproductive Output:* Golden eagles are detected engaging in behavior that indicates nesting has occurred (i.e. adults in incubation posture, nests with eggs/eggshells, nestlings or fledglings present).

- Evidence of territorial pairs includes observations of copulation, incubation, ruffled feathers on the belly during the incubation period (most conspicuous in females, and always when they’re flying), attending young, undulation displays by a pair, pair perching together, nest building or repair, attacking intruders, carrying prey, vocalizing to one another, and soaring together. All are strong evidence, but those underlined are more or less diagnostic. Observers should attempt to obtain multiple lines of evidence during visits to sites. Note that some of these behaviors do not require concurrent observation of both members of the pair.
  - When possible, the age of nestlings should be estimated using Hoechlin (1976; aging key provided in Driscoll 2010).
  - Nests are considered successful if fledglings are observed or nestlings reach 80% of the average fledgling age (Steenhof and Newton 2007), or 51 days old (Kochert et al. 2002).

*Aging Golden Eagles:* Based on the above age classification system, all golden eagles observed are recorded in one of the following seven age categories:

A = adult

S = subadult

J = juvenile

F = fledgling, nestling, brancher

UI = unknown immature

UA = unknown adult

U = unknown

*Juvenile* – Juvenile golden eagles have very dark, uniform plumage with the exception of the tail and wings. A white patch shows at the base of the tail, and will appear “clean” (i.e., it will lack any darker adult feathers, with an even boundary between white and dark). A white patch



may also be present on the wing at the base of the flight feathers, but is not present on all juvenile or older immature birds. No tawny bars are present on the upper-wings. White patches on the tail and wing are not visible on all perched birds. Juvenile birds can be aged when perched based on the lack of a tawny bar and overall uniform dark color.

*Sub-adult (older immature)* – golden eagles that display a partial or almost full tawny bar, yet show some white in the tail base or the wings. The white on the under-tail does not form a “clean” patch, rather some tail feathers will be replaced with darker adult feathers and show as dark or “dirty” spots on the tail. The center and outer most tail feathers are replaced before other tail feathers.

*Adult* – golden eagles are classified as adult if they displayed a full tawny bar on the wing and showed no white patches in the tail or wings, with the following exceptions. Adults could display white or gray bands in the tail. No white patches will be present on the wings, however, grayish feathers may form a “v” pattern on the under-wings in flight. Birds showing a “v” pattern may also have a gray tail band.

*Unknown immature (juvenile or older immature)* – This age class is used for golden eagles on which white was observed on the tail or wing, but a good view of the bird cannot be obtained, preventing aging to more specific age classes.

*Unknown adult (adult or older immature)* – golden eagles that display a tawny bar, but the tail or undersides of wings cannot be observed. White tail-coverts of juvenile or older immature birds are not visible on some perched birds.

*Unknown* – Birds that are confidently identified as golden eagles, but cannot be aged.

### Literature Cited

- Driscoll, D. 2010. Protocol for golden eagle occupancy, reproduction, and prey population assessment. American Eagle Research Institute, Apache Jct., AZ USA. 55pp.
- Hoechlin, D.R. 1976. Development of golden eaglets in southern California. *Western Birds* 7:137–152.
- Kochert, M. N., K. Steenhof, C. L. McIntyre, and E. H. Craig. 2002. Golden eagle (*Aquila chrysaetos*), *The Birds of North America Online* (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online.
- MacKenzie, D.I., J.D. Nichols, M.E. Seamans, and R.J. Gutierrez. 2009. Dynamic models for problems of species occurrence with multiple states. *Ecology* 90:823-835.
- Nichols, J.D., J.E. Hines, D.I. MacKenzie, M.E. Seamans, and R.J. Gutierrez. 2007. Occupancy estimation with multiple states and state uncertainty. *Ecology* 88:1395-1400
- Pagel, J. E., D. M. Whittington, and G. T. Allen. 2010. Interim golden eagle inventory and monitoring protocols and other recommendations. Division of Migratory Bird Management, US Fish and Wildlife Service.
- Steenhof, K., and I. Newton. 2007. Assessing nesting success and productivity. *Raptor research and management techniques*: 181-192.